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A FLOW FIELD STUDY FOR TOP MOUNTED INLETS ON FIGHTER AIRCRAFT C--ETC(U)
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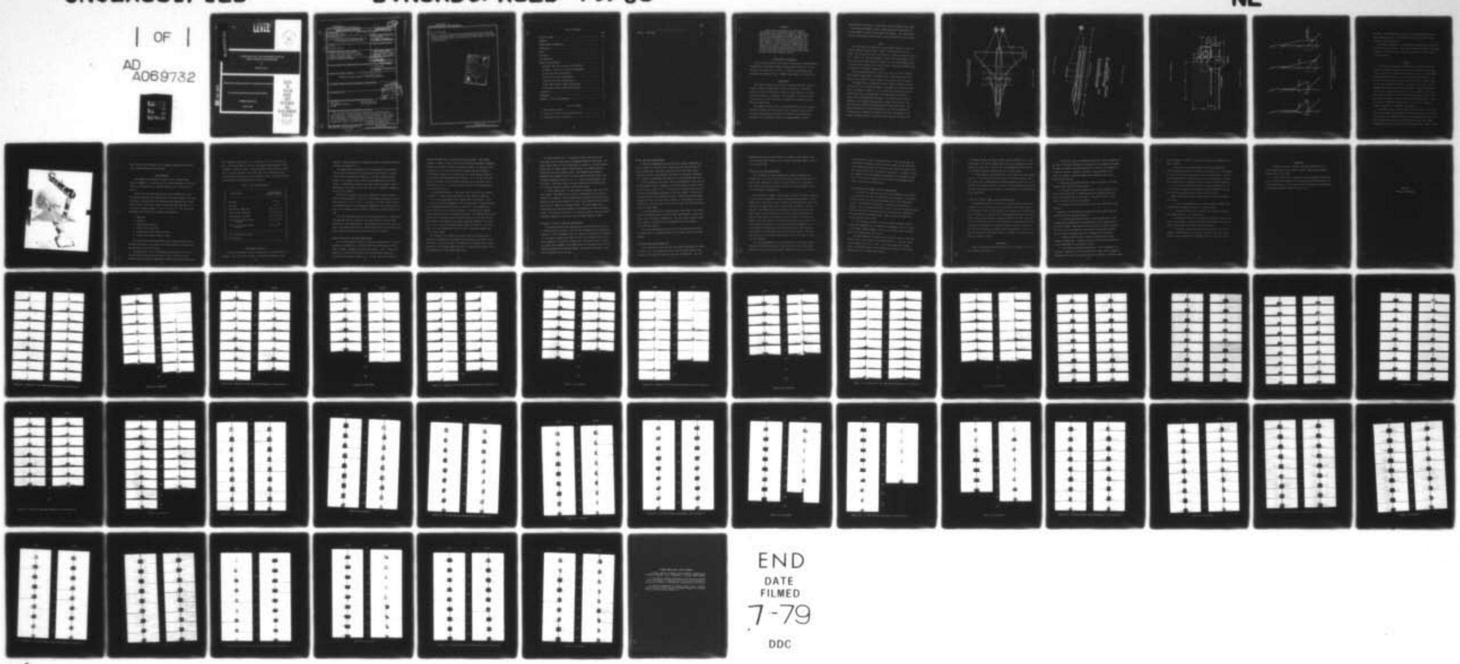

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A FLOW FIELD STUDY FOR TOP MOUNTED INLETS ON FIGHTER AIRCRAFT CONFIGURATIONS

by

Steven W. Prince

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AVIATION AND SURFACE EFFECTS DEPARTMENT

DTNSRDC/ASED-79/03

January 1979

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) DTNSRDC/ASED-79/03	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) A FLOW FIELD STUDY FOR TOP MOUNTED INLETS ON FIGHTER AIRCRAFT CONFIGURATIONS.		5. TYPE OF REPORT & PERIOD COVERED Final Report. Oct 1977 - Sep 1978.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Steven W./Prince		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS David W. Taylor Naval Ship R&D Center Aviation and Surface Effects Department Bethesda, Maryland 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element 62241N (17) Task Area WF 41 421 000 Work Unit 1-1600-078-22
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE (11) January 1979
		13. NUMBER OF PAGES 60 (12) 59p.
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report) (16) F41421

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Top Inlets
Leading Edge Extensions
Canards
Fuselage Flow Field
Flow Visualization

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A flow visualization study was conducted for top mounted inlets on fighter aircraft. A generic fighter model was tested at low speed in a wind tunnel with a tuft grid mounted on the upper fuselage. Tuft patterns were photographed in four longitudinal positions from 0- to 39-deg angle of attack and from 0- to 30-deg sideslip. Various configurations were tested with a high or low delta wing, two leading edge extensions and two

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canards. The results indicate that the downwash from leading edge extensions or canards can produce fairly smooth and straight flow to high angles of attack and moderate angles of sideslip for an inlet mounted on the upper fuselage surface.

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ABSTRACT

A flow visualization study was conducted for top mounted inlets on fighter aircraft. A generic fighter model was tested at low speed in a wind tunnel with a tuft grid mounted on the upper fuselage. Tuft patterns were photographed in four longitudinal positions from 0- to 39-deg angle of attack and from 0- to 30-deg sideslip. Various configurations were tested with a high or low delta wing, two leading edge extensions and two canards. The results indicate that the downwash from leading edge extensions or canards can produce fairly smooth and straight flow to high angles of attack and moderate angles of sideslip for an inlet mounted on the upper fuselage surface.

ADMINISTRATIVE INFORMATION

This study was authorized and funded by the Naval Air Systems Command (NAVAIR) 320D under Program Element 62241N and Task Area WF 41 421 000. The work was accomplished in FY 78 at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) under Work Unit 1-1600-078-22.

INTRODUCTION

This report presents flow field data of fighter aircraft configurations in the form of photographs of tuft grid patterns. Qualitative analysis of the flow conditions in terms of vortex behavior, flow direction, and turbulence is presented. The suitability of various configurations for a top inlet location is considered and recommendations are made for further study.

The objective of this study is to determine what aircraft configurations will produce good flow conditions for top mounted engine inlets. Top inlets have potential advantages in reducing hot gas reingestion problems of a vertical/short takeoff and landing fighter aircraft

operating near the ground. In this study, the upper surface flow fields of representative fighter aircraft configurations were investigated up to high angles of attack and high angles of sideslip. Flow visualization was done with surface tufts and with a tuft grid mounted on the fuselage.

MODEL

The wind tunnel test model was a simple generic model of a high performance fighter-attack aircraft. Figure 1 shows three views of the model. The fuselage was made of wood and had a constant elliptical section aft of Station 22. The nose tapered to circular sections forward of Station 22 with nose droop starting at Station 14. The canopy component had a constant half-circular section, which could be replaced by another piece to represent a "no canopy" configuration.

The wing configuration was a simple flat plate of 1/4-in. aluminum with rounded leading edges. The planform was a 45-deg sweep delta wing that could be mounted in either a high or low position on the fuselage.

Two canard and two leading edge extension (LEX) configurations were selected for the flow field experiments. The geometry of these configurations is presented in Figure 2. All of these model components were fabricated from 1/4-in. aluminum plate. The undersides were beveled to produce sharp leading and trailing edges. The canards were the fixed incidence, close coupled type designed to produce increased lift from the interaction between the canard generated vortex and the wing. The canard was mounted in the high position for a low wing configuration. A canard was not included for a high wing aircraft configuration. The canard configurations were a 45-deg delta platform and a 60-deg delta

Figure 1 - Three Views of Model
(Dimensions are in inches)

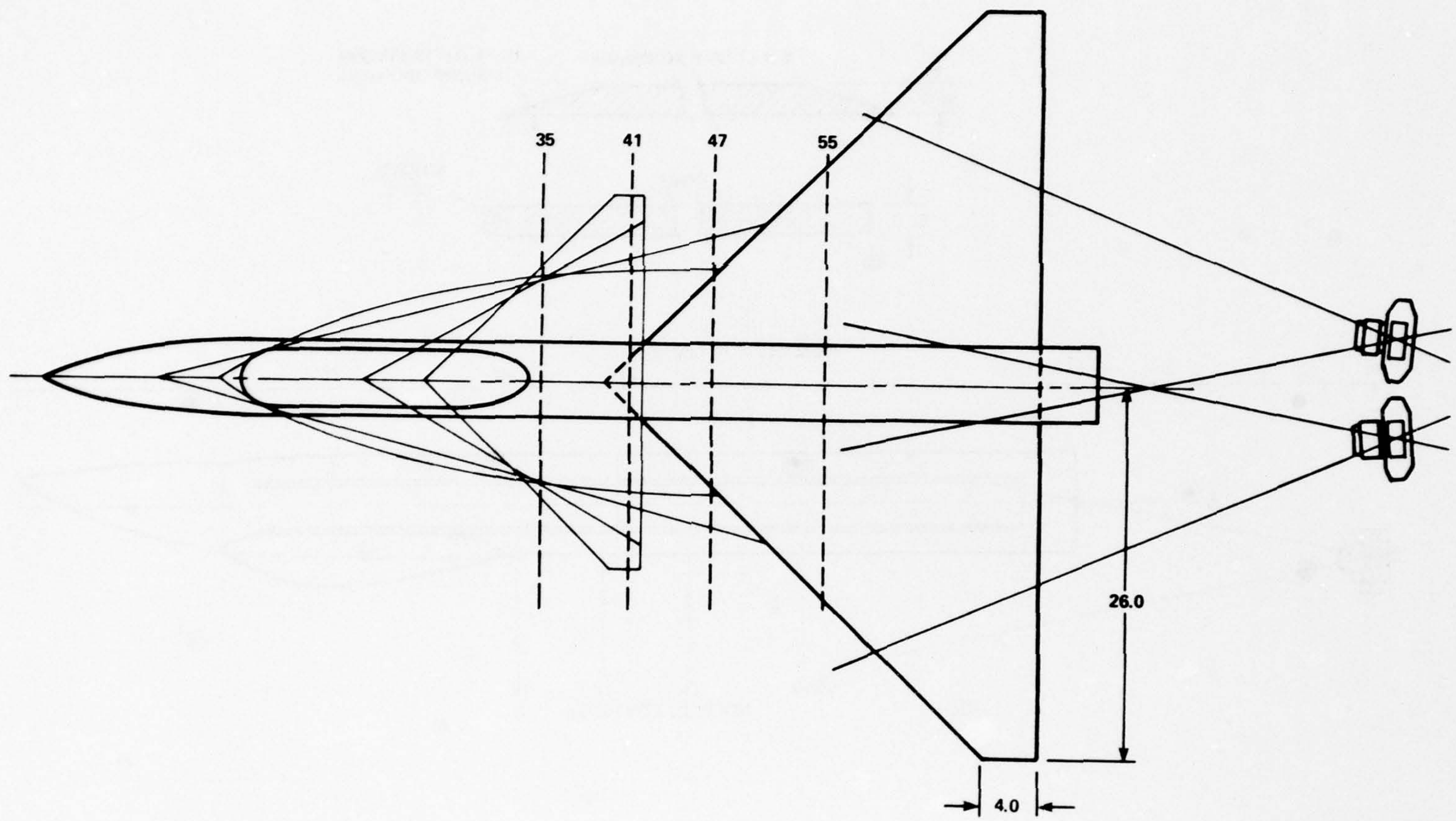

Figure 1a - Top View

Figure 1 (Continued)

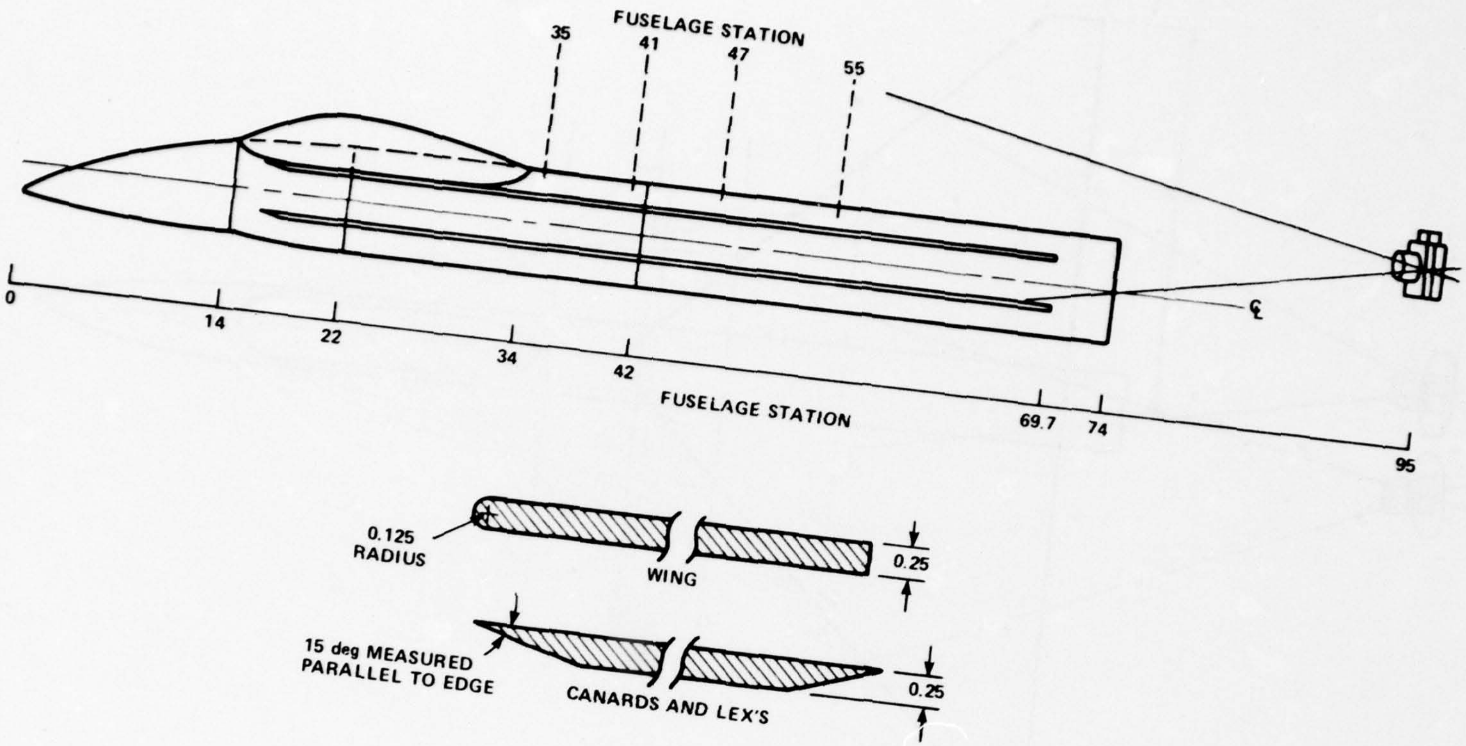

Figure 1b - Side View

Figure 1 (Continued)

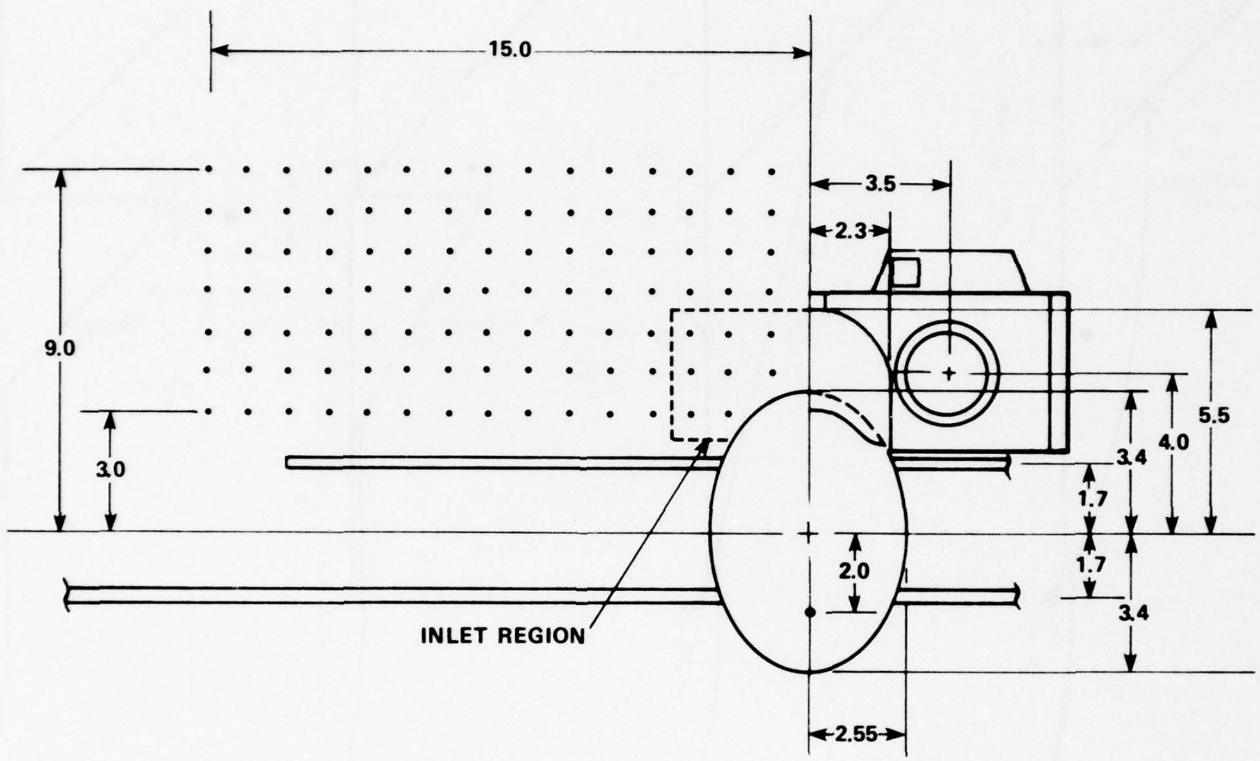

Figure 1c - Front View

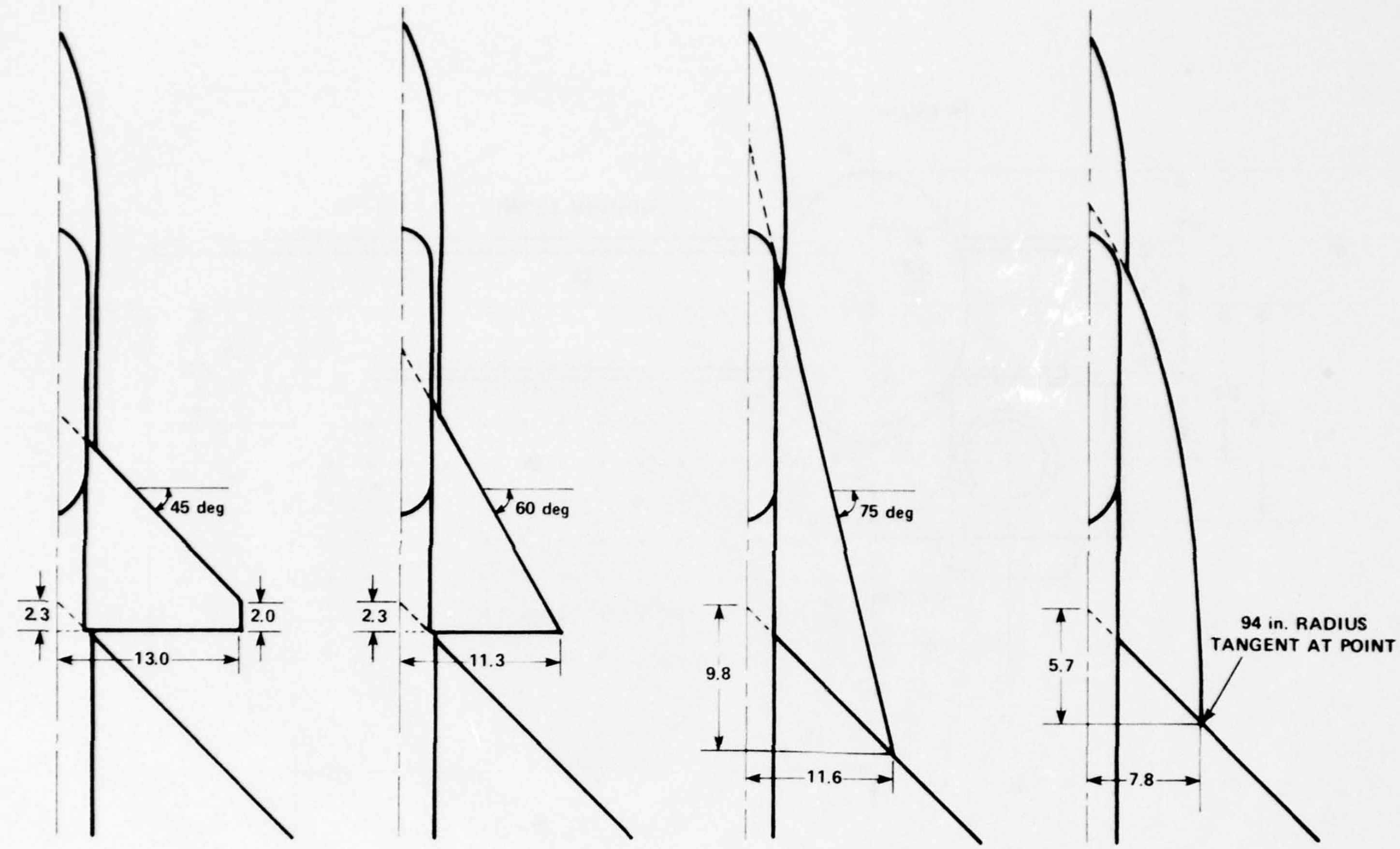

Figure 2 - Geometry of Leading Edge Extensions
and Canards
(Dimensions are in inches)

planform. The LEX configurations were a 75-deg sweep planform and an ogive planform, Figure 2. Both planforms could be mounted in either the high or low wing position.

The model was mounted on a sting support system attached to the wind tunnel ceiling; see Figure 3. The support system pivots about the ceiling attachment to pitch the model, and the turntable in the ceiling rotates to yaw the model.

EQUIPMENT

The tuft grid was designed for analysis of sections of the flow field above the model where top inlets may be located. The tuft grid could be mounted at 11 longitudinal positions at 2-in. intervals between fuselage Stations 35 and 55. The tuft grid had a half-span of 15 in. (38.1 cm) with a vertical coverage of 6 in. (15.2 cm). Figure 3 shows the tuft grid attached to the model. The frame of the tuft grid was designed for minimum interference on the model. The frame was made of 1/8- by 3/4-in. spring steel with 1/4- by 1-in. supports. Fine wires were strung from the two sides of the frame with small springs to provide tension. Tufts of yarn were tied to the wire and glued in place. The length of each tuft varied between 1 and 1-1/2 in. The tufts formed a pattern of 1 in. squares; see Figure 1c.

To provide a view of the flow field from the "point of view" of the inlet, two motorized 35-mm cameras were mounted on the main support aft of the model. The cameras were mounted on the sting so that each moved with the model axis as the model was pitched or yawed. Each camera photographed one side of the tuft grid. By mounting the cameras in line

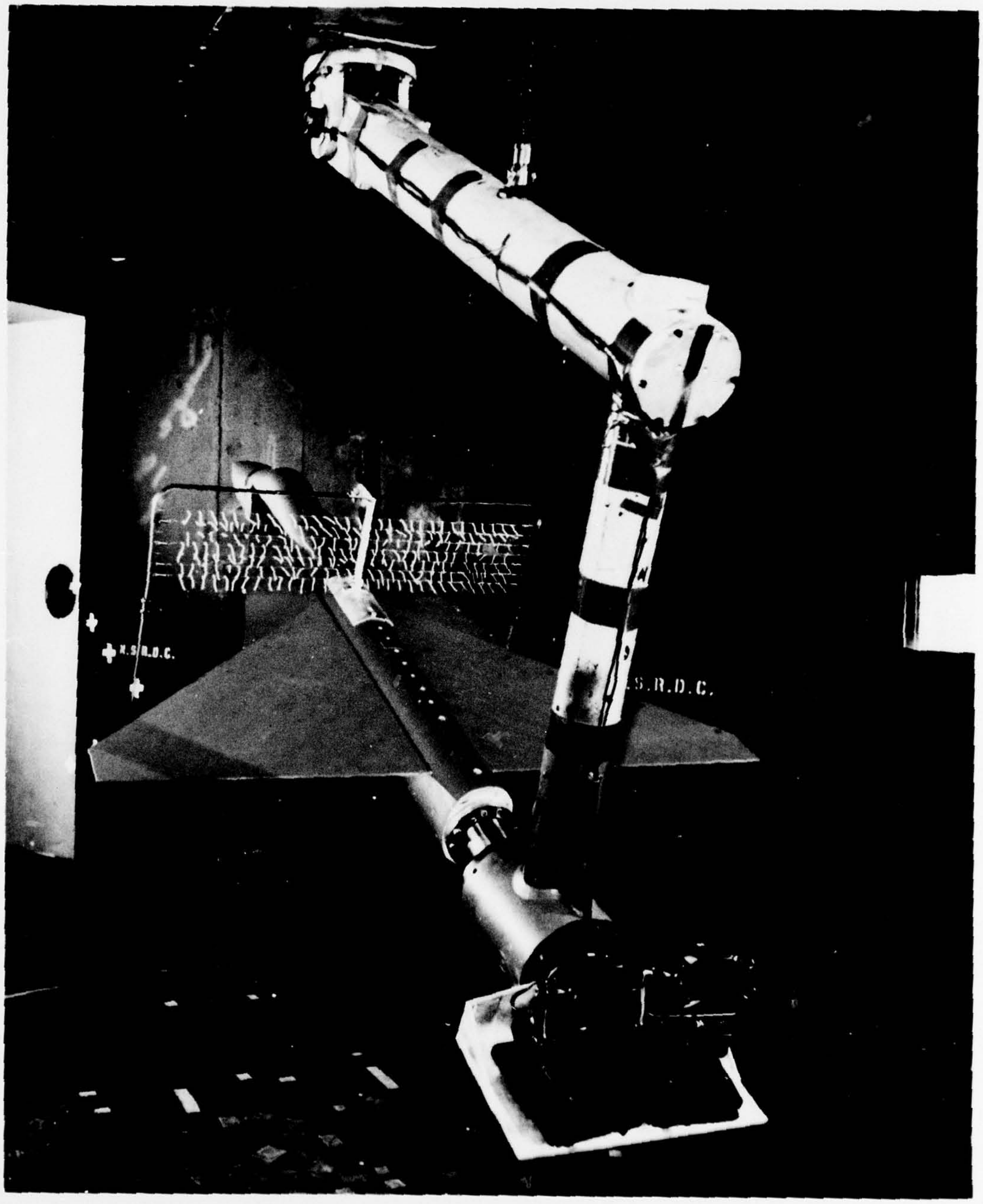

Figure 3 - Wind Tunnel Model Installation

with the inlet region (Figure 1c), any angular distortion of the tufts due to camera perspective was minimized.

TEST PROCEDURE

The evaluation was conducted in the 8- by 10-ft subsonic wind tunnel at DTNSRDC. All tests were run at a tunnel velocity of 107 ft/sec (32.6 m/s) corresponding to a Reynolds number of 0.97 x 10^6/ft (3.18 x 10^6/m).

Initial test runs were conducted with tufts attached both to the side and top surfaces of the fuselage and to the upper surface of the wing and canards. The resultant tuft patterns were photographed with a movie camera located in the tunnel window. Pitch sweeps were made from $\alpha = 0$ to 39 deg for sideslip angles, β of 30, 20, 10, 0, -10, -20, and -30 deg. PHotographs were taken of the following configurations.

1. High Wing
2. Low Wing
3. Ogive Strake, High Wing
4. 75-deg Strake, High Wing
5. 60-deg Close Coupled Canard, Low Wing
6. 45-deg Close Coupled Canard, Low Wing

The tuft grid was initially mounted on the high wing configuration to determine interference of the grid on the model; however, no interference was noticeable in the surface tufts.

The primary part of the test program was concentrated on recording the upper surface flow field with the tuft grid. The tuft grid was installed in four different longitudinal positions for most configurations.

Pitch sweeps were made from α = 0 to 39 deg at β = 0, -10, -20, and -30 deg. Still photographs were taken by the sting mounted cameras in 5-deg increments of angle of attack. Extreme turbulence from the model at high angles of attack sometimes vibrated the tuft grid excessively and prevented adequate recording of the tuft pattern. Table 1 lists the aircraft configurations and corresponding grid positions.

TABLE 1 - TEST GRID POSITIONS

Configuration	Grid Positions (Fuselage Station)
High Wing	41, 47
Low Wing	41, 47
Ogive Strake, High Wing	35, 41, 47, 55
75-deg Strake, High Wing	35, 41*, 47, 55
75-deg Strake, Low Wing	35, 41, 47, 55
60-deg Close Coupled Canard, Low Wing	35, 41, 47, 55
45-deg Close Coupled Canard, Low Wing	35, 41, 47**

*Also tested with no canopy

**α = deg only

RESULTS AND DISCUSSION

Tuft grid photographs of seven configurations are presented in the Appendix. The 75-deg LEX, high wing configuration was chosen as the

baseline. This configuration is described in detail and the other configurations are compared to it.

The upper surface flow field of each configuration is described in terms of general characteristics and the effects of sideslip. Observations include flow directions, behavior of the LEX or canard vortices, behavior of the canopy vortex, and flow field properties in the inlet region. A representative shape of the inlet region is shown in Figure 1c. Assessment of flow quality in the inlet region is a subjective judgment on the part of the author.

The data are arranged in sets by configuration, and are arranged in subsets by grid positions. Each set of facing pages contains data for one grid position at $\beta = 0$, $\beta = 10$, $\beta = -20$, and $\beta = -30$ deg. Thus, the flow field characteristics for a prospective longitudinal inlet position can be seen for the complete angle of sideslip and angle of attack envelope evaluated.

The flow field characteristics at each grid position of a configuration were generally similar; therefore, each grid position is not described separately for each configuration. Significant fore and aft variations are noted. The reader should refer to fuselage Station 41 of each configuration while reading the discussion rather than refer to all stations.

BASELINE 75-DEG LEX, HIGH WING CONFIGURATION

Data for the baseline 75-deg LEX, high wing configuration are shown in Figures A.1a through A.1d. At 0-deg sideslip and 0-deg angle of attack there is smooth, straight flow in the inlet region. At $\alpha = 5$ deg, small symmetrical vortices develop off the port and starboard leading edge extensions, becoming more apparent at $\alpha = 10$ deg. The vortices spread

outboard and vertically as they move aft along the wing. With further increases in angle of attack, the vortices intensify and produce a downwash relative to the model centerline in the inlet regions. At Station 55 with the model at α = 25 deg, the vortex core becomes turbulent and bursts. This turbulent vortex core or burst vortex core moves forward through the grid positions with increasing angle of attack. At α = 35 deg, the inlet region for Stations 47 and 55 becomes turbulent due to the burst flow in the vortex core. At α = 39 deg, the flow at Station 41 is also affected by the burst vortex core.

At 10-deg sideslip and α = 0 deg some cross flow in the inlet region is apparent. A small vortex originating from the canopy is visible at α = 5 and 10 deg superimposed on the leeward image of the canopy. After α = 10 deg, this vortex disappears. This vortex appears in the inlet region at all longitudinal positions except at Station 55, and is probably too weak to drastically affect inlet performance. The LEX vortices develop slightly leeward of their zero sideslip positions. The windward vortex gets larger with aft position, while the leeward vortex stays the same size and moves upwards. The windward vortex adds a downwash component to the cross flow. At α = 20 deg, the windward vortex bursts at Station 55. The burst vortex core moves forward with angle of attack, producing turbulent flow in each inlet region.

The behavior of the windward and leeward vortices when the model is yawed can be understood by considering the sweep angle of each side of the LEX relative to the free stream. The windward vortex behaves like a vortex generated by a less highly swept wing, and the leeward vortex behaves like a vortex generated by a more highly swept wing.

At 20-deg sideslip and $\alpha = 0$ deg there is more cross flow in the inlet region, and a canopy vortex is generated leeward of the canopy. The canopy vortex enters the inlet region only at Station 35. The LEX vortices develop more to leeward than at 10-deg sideslip. The leeward vortex is much smaller than the windward vortex. The windward vortex produces downwash on the windward side of the inlet regions, while only cross flow is produced leeward at Station 55 for $\alpha = 15$ deg, and the windward vortex core bursts. This burst vortex core moves forward with increasing angle of attack and produces turbulence in each inlet region.

At 30-deg sideslip and $\alpha = 0$ deg, there is excessive cross flow in the inlet region. The canopy vortex is more to leeward and out of the inlet region at all stations. With increasing angle of attack, the canopy vortex becomes as large as the windward LEX vortex. The leeward LEX vortex is very small and just leeward of the canopy vortex. The inlet regions "see" a strong cross flow with some downwash on the windward side from the windward vortex. The vortex core bursts at $\alpha = 15$ deg, Station 55, and moves forward producing turbulence in each inlet region at higher angles of attack.

NO CANOPY, 75-DEG LEX, HIGH WING CONFIGURATION

The 75-deg LEX, high wing configuration was tested without the canopy to determine canopy influence. Data for this configuration are presented in Figure A.2. This configuration was only tested with the tuft grid at Station 41. The results indicate that there is very little difference in the flow field compared to the baseline configuration. No canopy vortex is present, but a small vortex appears in the same position as the canopy vortex on the baseline configuration at 20-deg sideslip. This vortex is probably formed off of the upper part of the nose.

NO LEX, HIGH WING CONFIGURATION

A high wing configuration without LEX's was tested to determine the effect of LEX's on the flow field. Figures A.3a and A.3b show data for this configuration. These data indicate that the flow field is quite different from the vortex dominated flow field of the baseline configuration. There is considerably more upwash in the near-fuselage flow field.

At 0-deg sideslip, twin canopy vortices (superimposed on the canopy in the photographs) reduce the upwash in the inlet region; but these vortices are in the inlet region. At $\alpha = 35$ deg, the flow separates off the top of the fuselage and produces turbulence in the inlet region. At Station 47, turbulent vortices are forming off the wing. These vortices help produce straighter flow in the inlet region, that is, no flow angularity relative to body axis, until the angle of attack is such that the vortex turbulence enters the inlet region.

At 10-deg sideslip, only a leeward canopy vortex forms. This vortex rises with increased angle of attack, because no downwash is present like there is in the baseline configuration. The inlet region flow has significant upwash. At Station 47, the windward wing vortex turbulence enters the inlet region.

Flow field characteristics for 20- and 30-deg sideslip are similar to characteristics at 10-deg sideslip with the canopy vortex moving more leeward.

OGIVE LEX, HIGH WING CONFIGURATION

Flow field data for the ogive LEX, high wing configuration are shown in Figure A.4. This configuration has flow field characteristics very similar to the baseline 75-deg LEX, high wing configuration. The main

differences are that the LEX vortices are slightly closer together, and the vortex core bursts usually occur at about 5 deg higher angle of attack for the ogive strake.

75-DEG LEX, LOW WING CONFIGURATION

The 75-deg LEX, low wing configuration is shown in Figures A.5a through A.5d. The vortices develop in the same position on the wing as on the baseline configuration but are lower in relation to the fuselage. Thus, these vortices do not affect the flow in the inlet regions as much as on the baseline configuration.

When the model is yawed, a higher angle of attack is reached, compared to the baseline configuration, before the windward vortex bursts. This is probably due to the "wall" effect created by the fuselage sides. The fuselage sides straighten the overall flow to reduce the effect of aircraft sideslip. The canopy vortex is also present and affects the flow in the inlet region a little more than it does on the baseline configuration. When the canopy vortex is leeward of the inlet region, it increases the upwash in the inlet region. In the two forward stations, the flow in the inlet region is parallel to the centerline rather than downward as it is on the baseline configuration. With sideslip, there is both upwash and cross flow in the inlet regions in the two forward stations. The downward influence of the vortices changes this to only cross flow in the two aft inlet regions.

An inlet arrangement other than top mounted on the fuselage appears possible with this configuration. Side inlets of a tall, narrow shape (similar to the inlets of the McDonnell Douglas F-4 aircraft) may perform

satisfactorily in the two forward positions. The tuft grid does not extend down far enough to cover this inlet region, but the flow field can be imagined from the tuft directions near this region and the flow field characteristics of the baseline configuration. At angle of attack, the windward side would probably see downwash from the windward vortex until it bursts; the leeward side would probably see downwash from the leeward vortex and the canopy vortex.

60-DEG CLOSE COUPLED CANARD, LOW WING CONFIGURATION

In Figures A.6a through A.6d, flow field photographs for the 60-deg close coupled canard, low wing configuration are presented. For the two forward stations, the tuft grid photographs show a vortex development similar to the baseline configuration, except that the vortices are smaller. At the two rearward stations, which are aft of the canard trailing edge, the vortices do not spread apart as on the baseline configuration but maintain the same distance apart. These vortices also take on an oblong shape aft of the canard.

At zero sideslip, the flow in the inlet region is mostly straight rather than downwash as for the baseline configuration. This is a result of the reduced vortex strength. The flow in the inlet regions is fairly good in all stations up to α = 39 deg.

At 10-deg sideslip, the canopy vortex is always present in the inlet regions. The vortex starts on the leeward side at α = 5 deg and crosses to the windward side at α = 15 deg. In the two forward inlet regions cross flow exists; however, the flow becomes more parallel to the model centerline for the rearward inlet regions.

At 20-deg sideslip, the canopy vortex is on the leeward side. In the inlet regions, the vortex produces some upwash on the leeward side which reduces the cross flow. At Station 55, the windward LEX vortex crosses the centerline producing turbulent flow in the inlet region.

At 30-deg sideslip, the canopy vortex is much larger than the leeward vortex. In the two forward positions, mostly cross flow exists in the inlet region, but it diminishes with increasing angle of attack due to the influence of the canopy vortex. At Station 47, the windward vortex drifts into the inlet region; and at Station 55, this vortex is on the leeward side of the centerline.

45-DEG CLOSE COUPLED CANARD, LOW WING CONFIGURATION

Photographic data for the 45-deg close coupled canard, low wing configuration is very similar to that of the 60-deg close coupled canard. The difference is that the LEX vortices on the 45-deg close coupled canard have a turbulent core from the onset. The turbulent vortices cause turbulence in the inlet region which increases gradually with angle of attack. The flow in the inlet regions for the 45-deg close coupled canard configuration is not satisfactory to as high an angle of attack as compared to the flow for the 60-deg close coupled canard configuration. Because of the high turbulence in the inlet regions, a complete set of data was not taken at Stations 47 and 55.

CONCLUSIONS

Based on the qualitative data obtained in this low-speed flow field test, general conclusions are:

1. At angle of attack, the downwash produced by a LEX or canard makes the flow on the upper fuselage fairly parallel to the fuselage centerline. The degree of upwash or downwash desired for an inlet can be obtained by varying the vertical location of the LEX or canard relative to the inlet; for example, a high LEX produces more downwash (in the inlet region) than a low LEX.

2. The weak vortex produced by the canopy is usually in the upper fuselage inlet region at 10-deg sideslip.

3. The flow in the upper fuselage region is fairly good until the angle of attack and angle of sideslip where the turbulent core of the LEX or canard encroaches on this region. This effect occurs at lower angles of attack in the more aft regions.

4. Excessive cross flow is present in all inlet regions at 30-deg sideslip.

Several of the configurations evaluated provide satisfactory flow characteristics for top mounted inlets:

1. The 75-deg High Wing LEX and Ogive LEX Configurations: These configurations provide good flow characteristics over a large angle of attack and sideslip range and have the best angle of attack performance. The flow in the inlet regions is down, rather than straight; however, this may cause a favorable reduction in boundary layer thickness.

2. High Wing Configuration: Upwash and canopy vortices make Station 41 undesirable. Turbulence from the wing vortices makes Station 47 also undesirable at high angle of attack.

3. The 75-deg Low Wing LEX Configuration: This configuration is good over a large angle of attack and sideslip range. This configuration demonstrated the best flow characteristics with sideslip. Excessive upwash

may be generated at Station 35, but fairly parallel flow appears at the other stations.

4. The 60-deg Close Coupled Canard, Low Wing Configuration: This configuration produces satisfactory flow quality over a large angle of attack and sideslip range; however, the flow characteristics at the two rearward positions are unsatisfactory at 30-deg sideslip. Flow is fairly straight with turbulence from the canards increasing gradually.

5. The 45-deg Close Coupled Canard, Low Wing Configuration: The flow is fairly straight with turbulence increasing gradually; however, the flow becomes unsatisfactory at high angles of attack.

Based on experience gained in this study, the following comments are offered:

1. A wider fuselage may serve to create a wider acceptable inlet region without changing the shape of the LEX or canard.

2. A smaller LEX than the two evaluated may produce acceptable flow characteristics in the inlet region.

3. Negative deflection of the canards may improve the inlet flow field at high angles of attack by preventing the canards from stalling, which should improve the 45-deg canard configuration.

4. The canopy vortex may possibly be directed out of the inlet region. A swept delta fin on top of the canopy may cause the canopy vortex to form higher above the fuselage and out of the inlet region.

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2. Lacey, D.W. and S.J. Chorney, "Subsonic Aerodynamic Characteristics of Close Coupled Canards with Varying Area and Position Relative to a 50-deg Swept Wing," David W. Taylor Naval Ship Research and Development Center Report ASED-199, AD 882 702 (Mar 1971).

APPENDIX A

TUFT GRID PHOTOGRAPHS

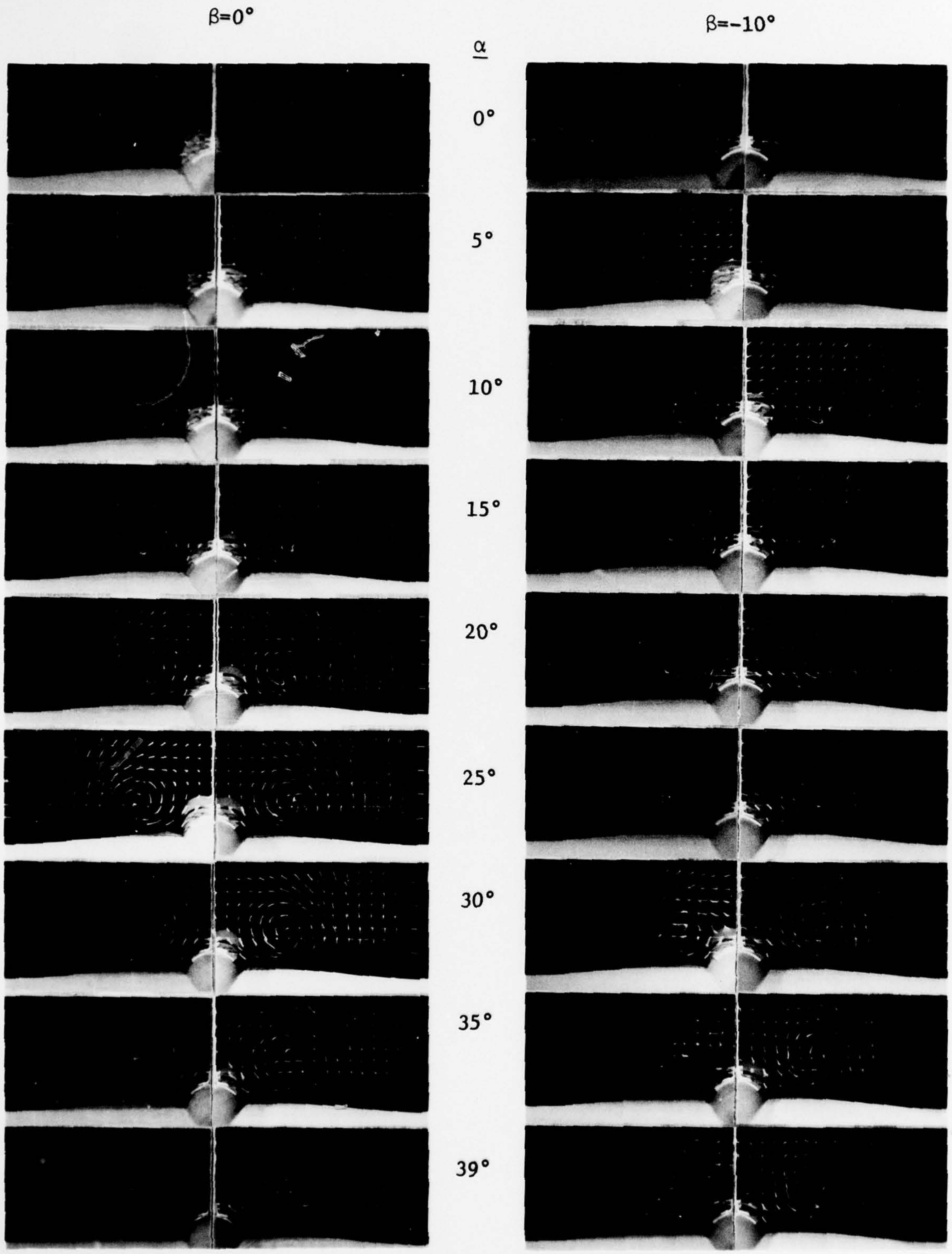
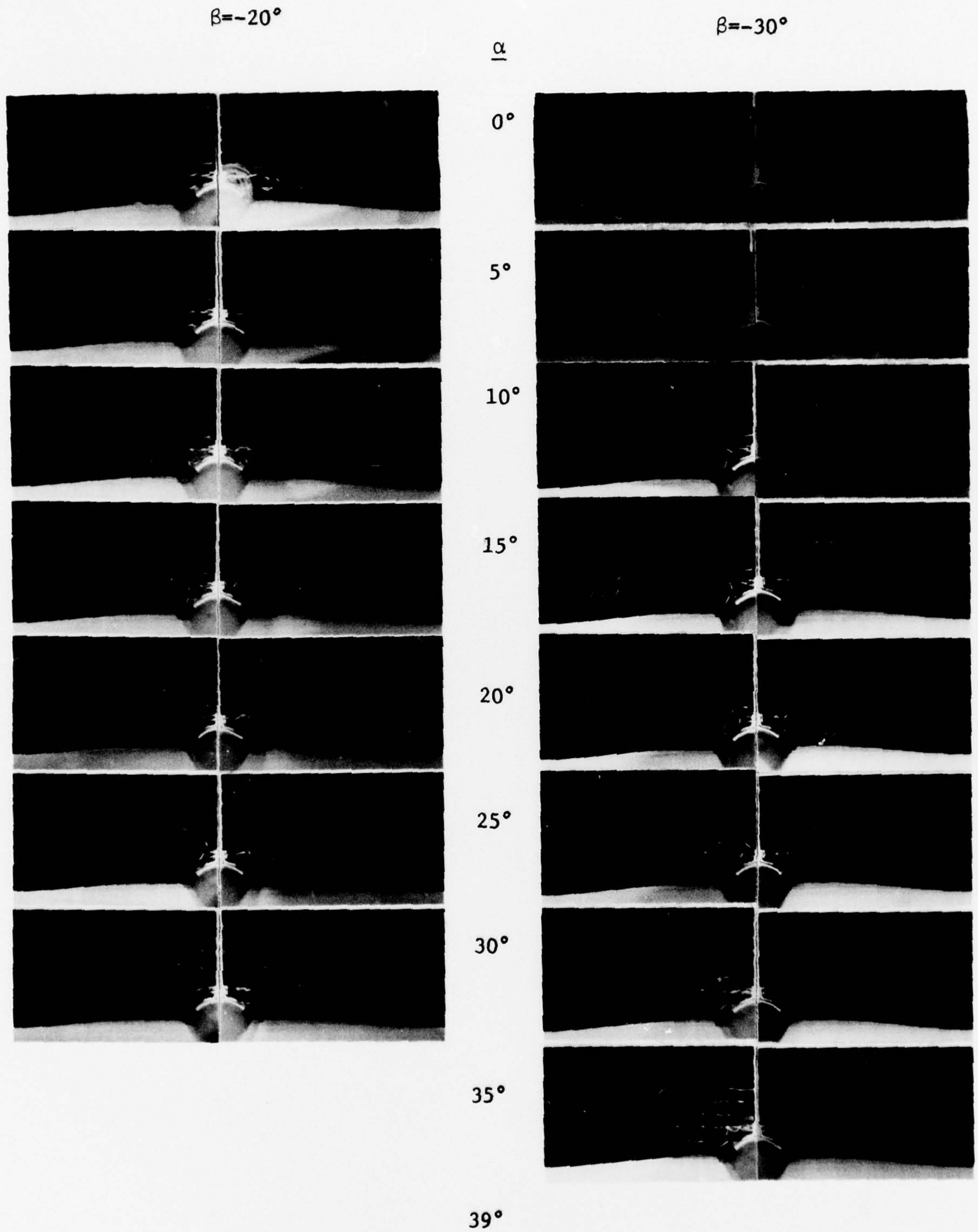


Figure A.1a - Baseline 75° LEX, High Wing Configuration, Grid Position 35



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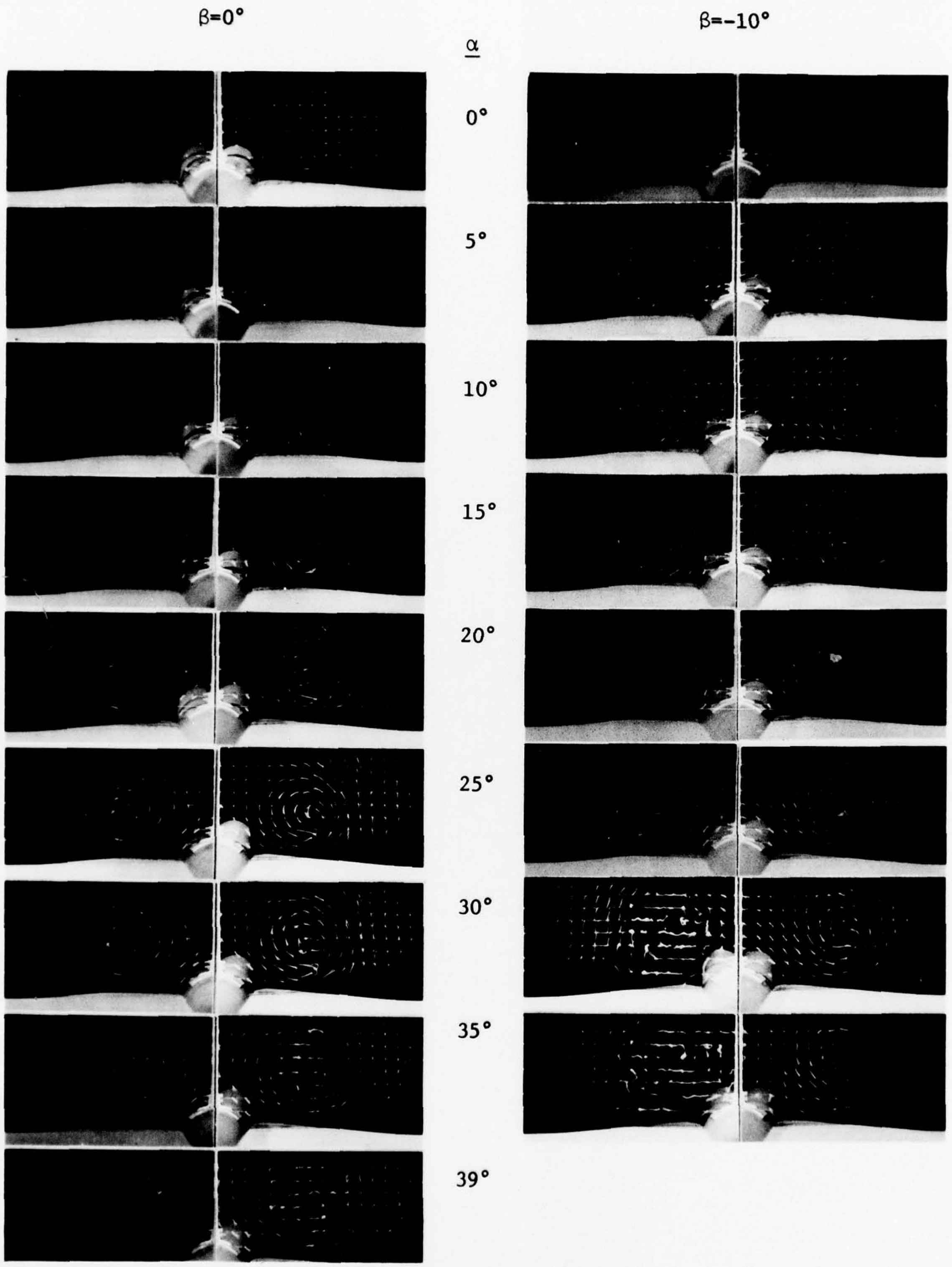
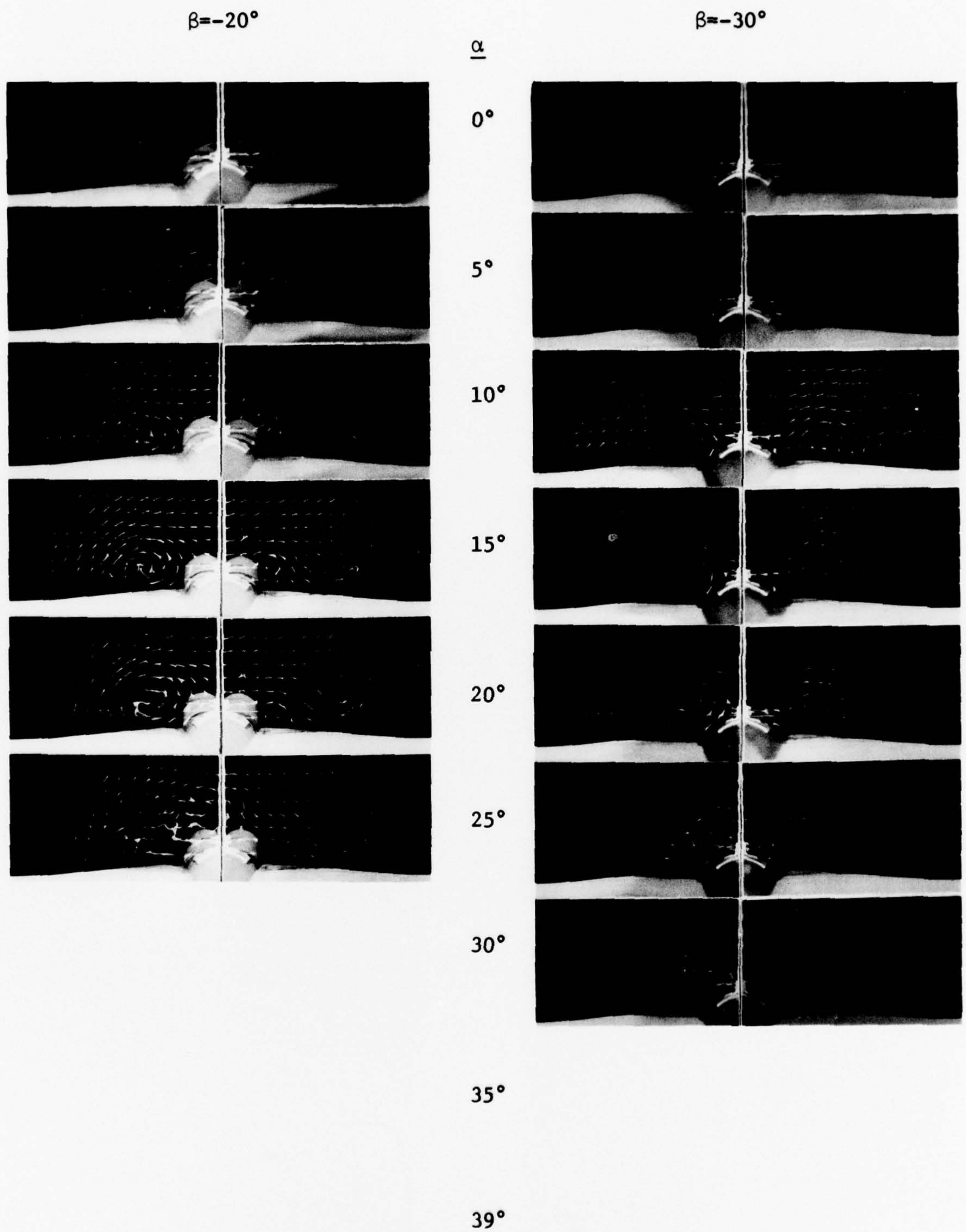


Figure A.1b - Baseline 75° LEX, High Wing Configuration, Grid Position 41



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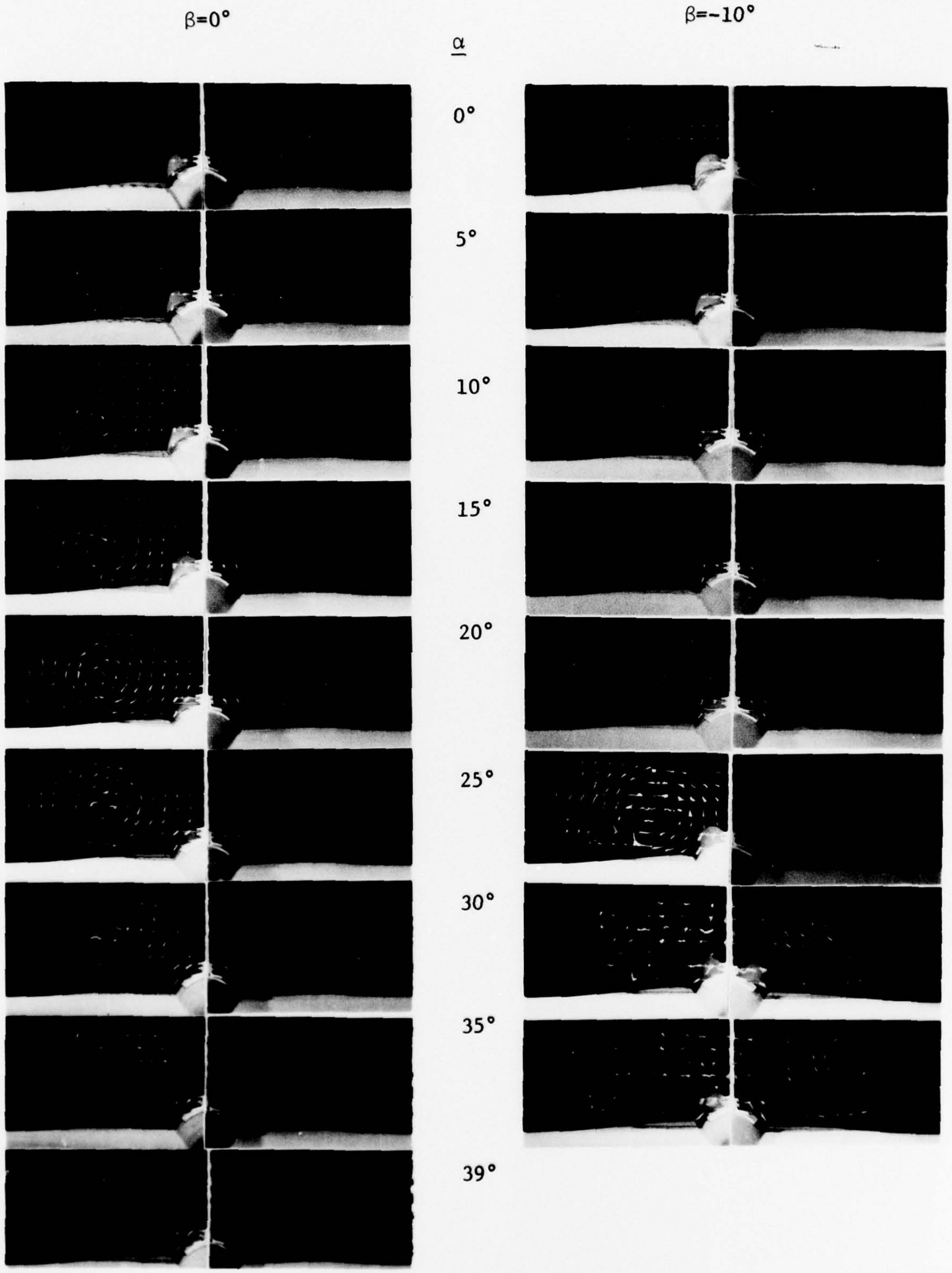


Figure A.1c - Baseline 75° LEX, High Wing Configuration, Grid Position 47

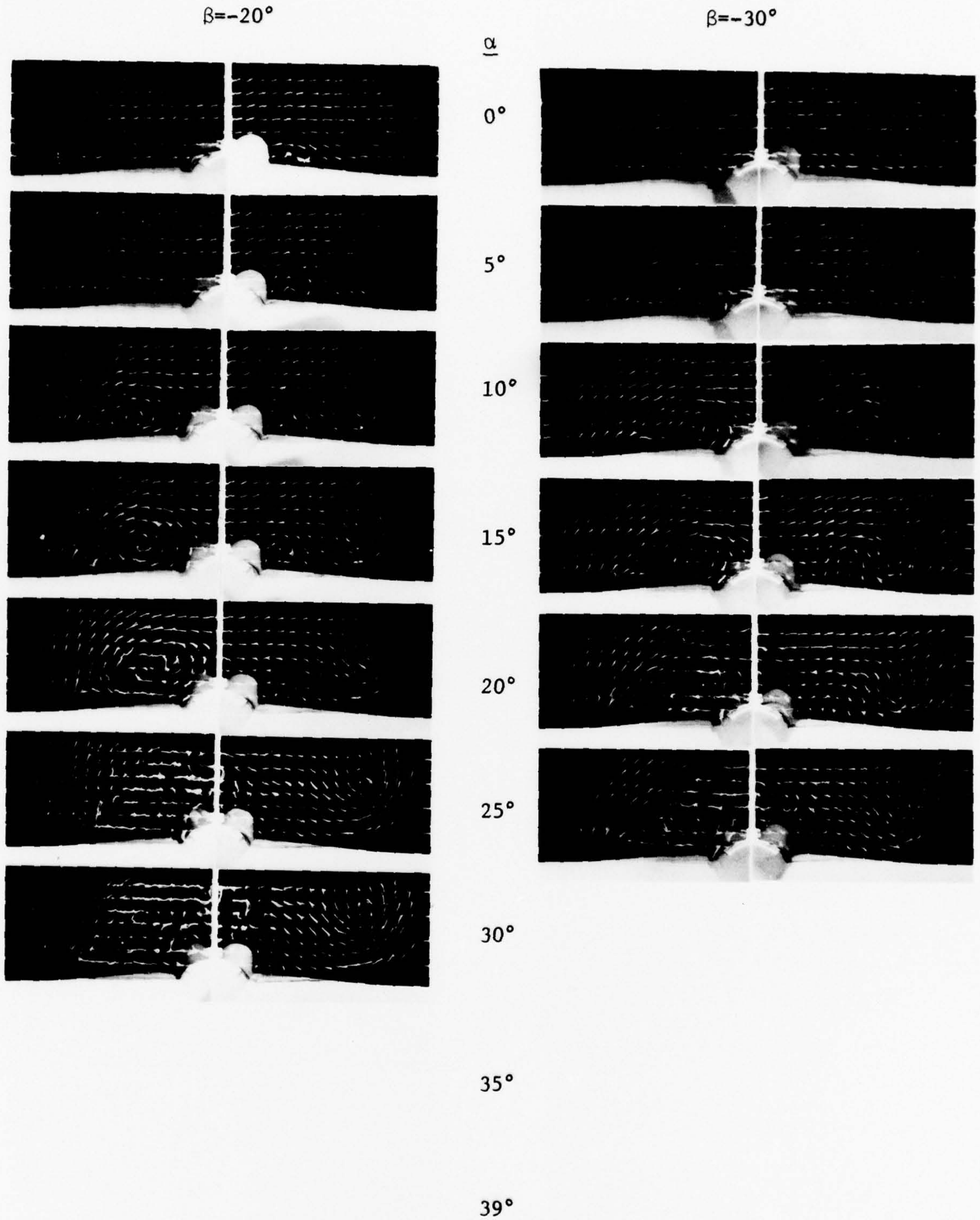


Figure A.1c (Continued)

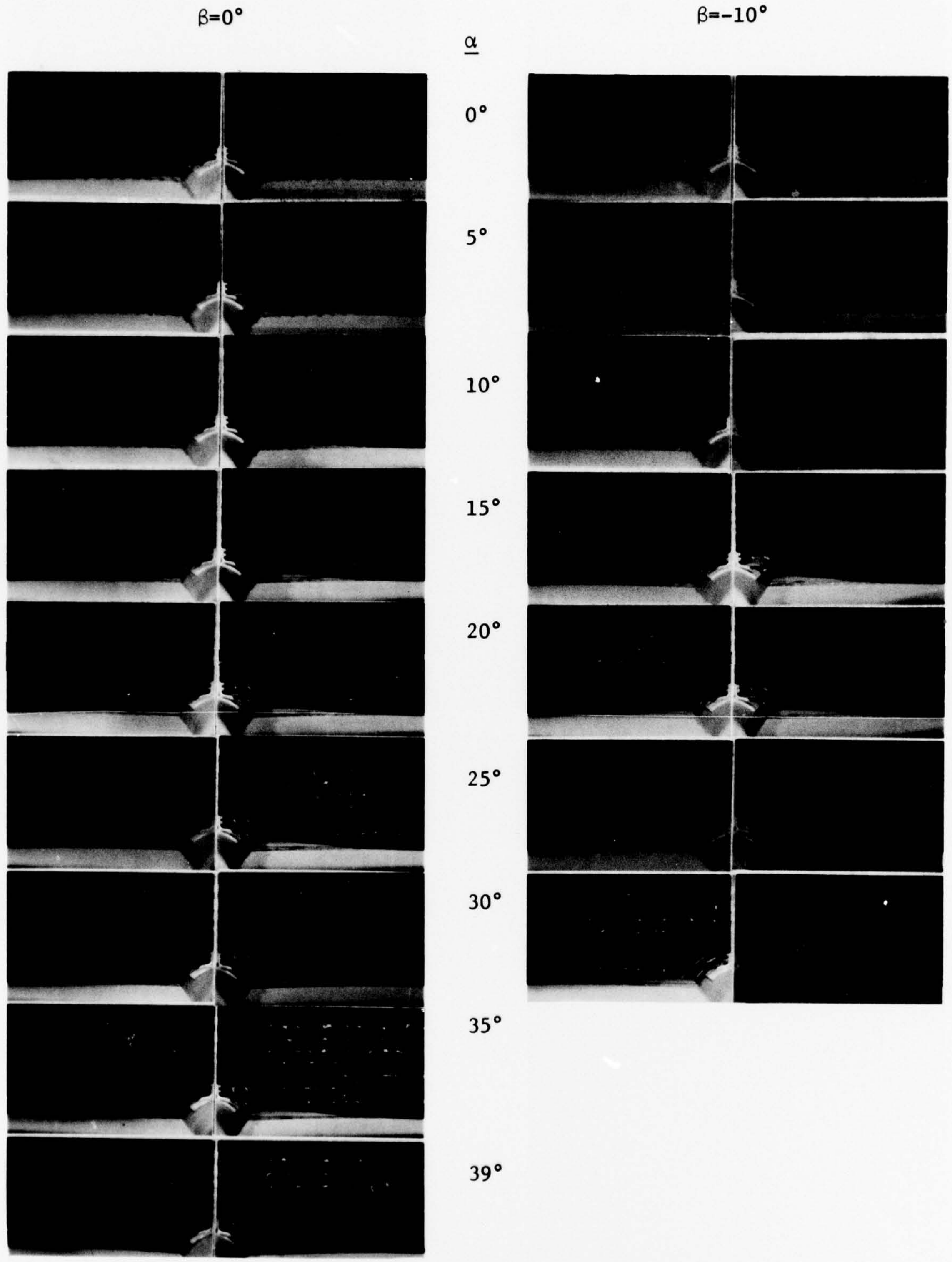
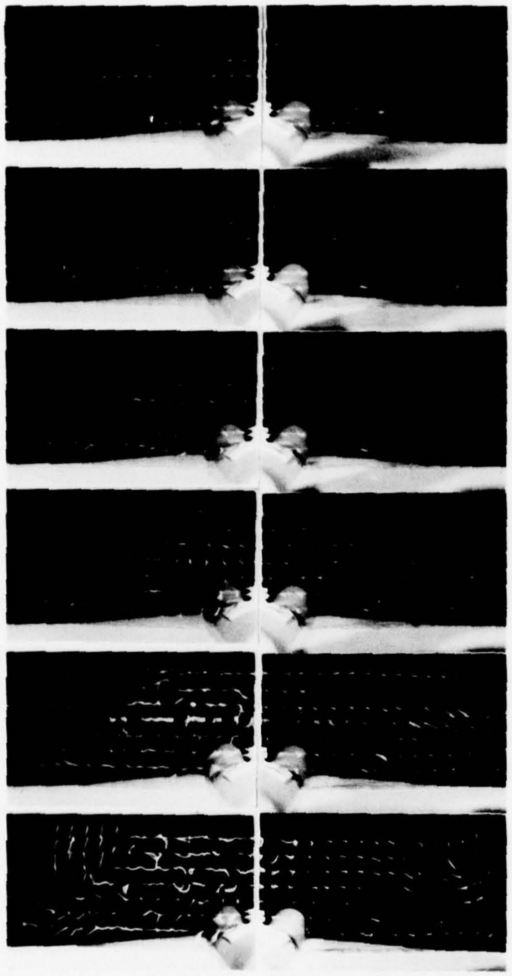
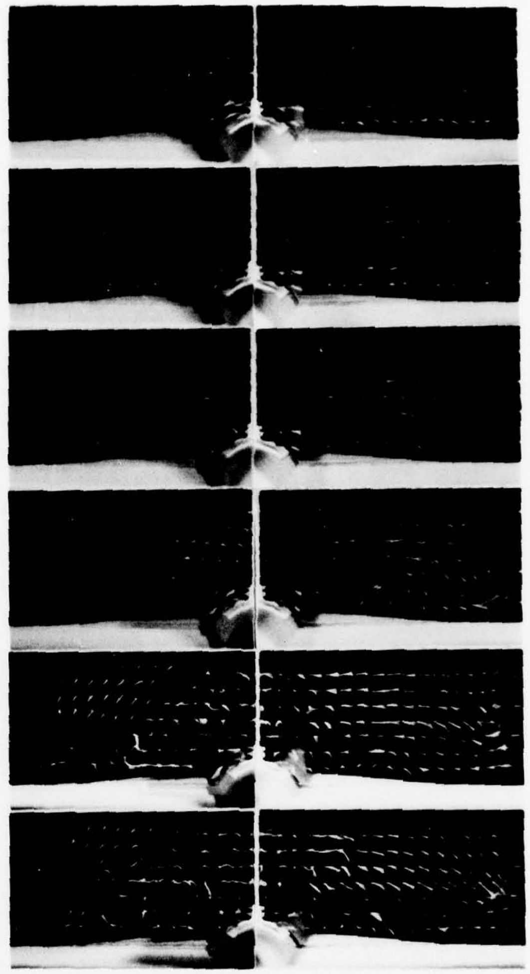


Figure A.1d - Baseline 75° LEX, High Wing Configuration, Grid Position 55

$\beta=-20°$ $\beta=-30°$

$\underline{\alpha}$





0°

5°

10°

15°

20°

25°

30°

35°

39°

Figure A.1d (Continued)

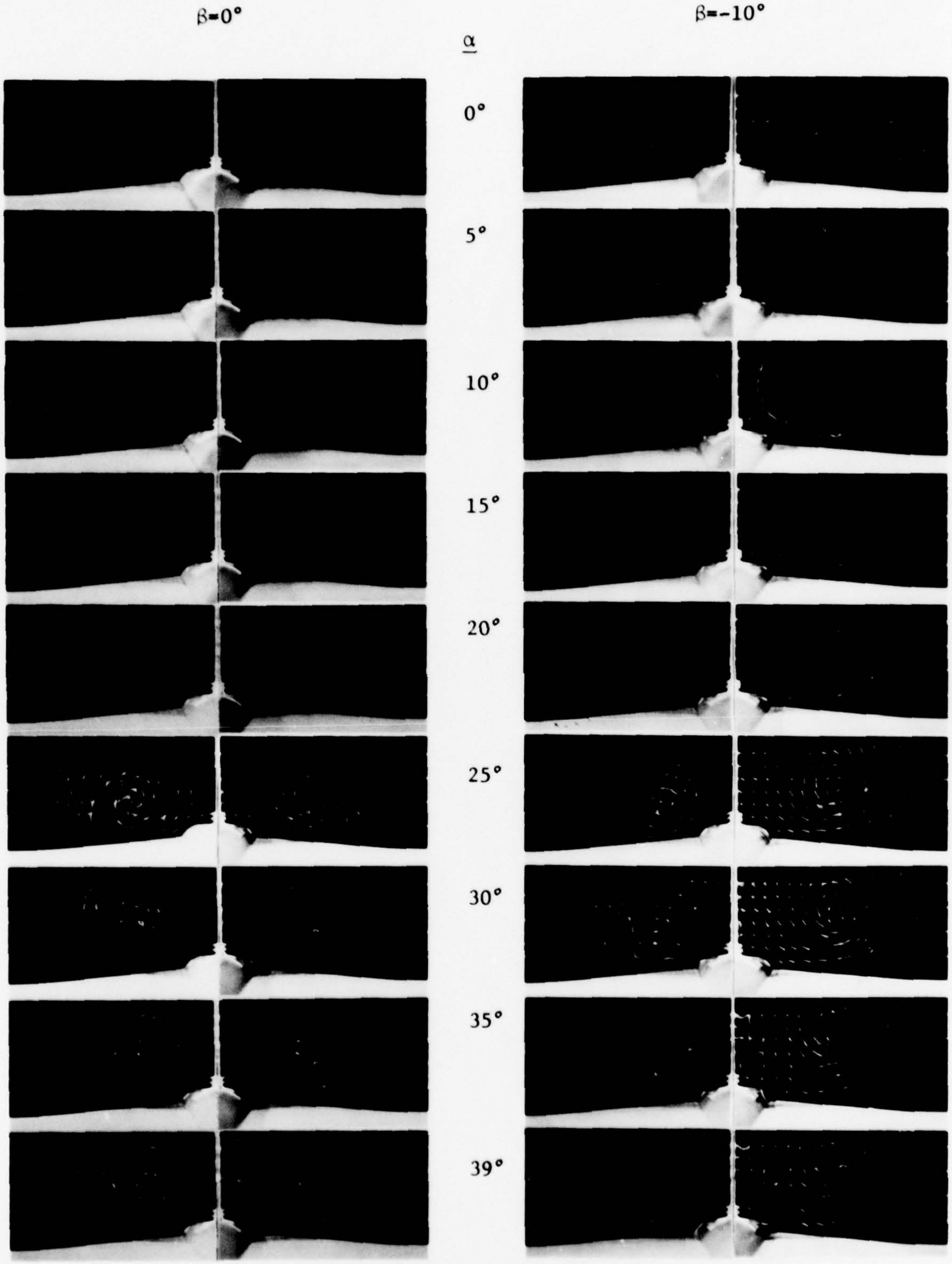


Figure A.2 - No Canopy, 75° LEX, High Wing Configuration, Grid Position 41

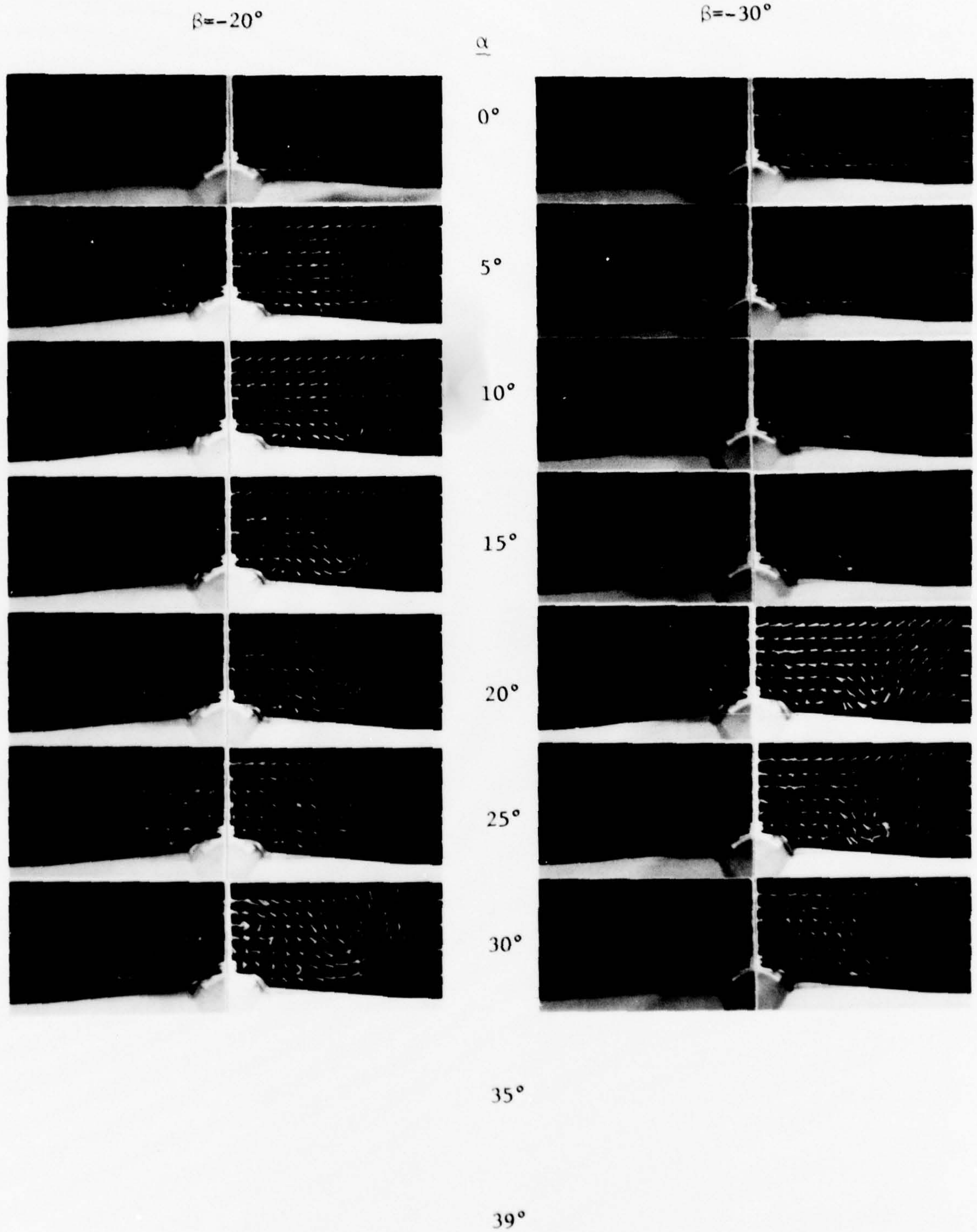


Figure A.2 (Continued)

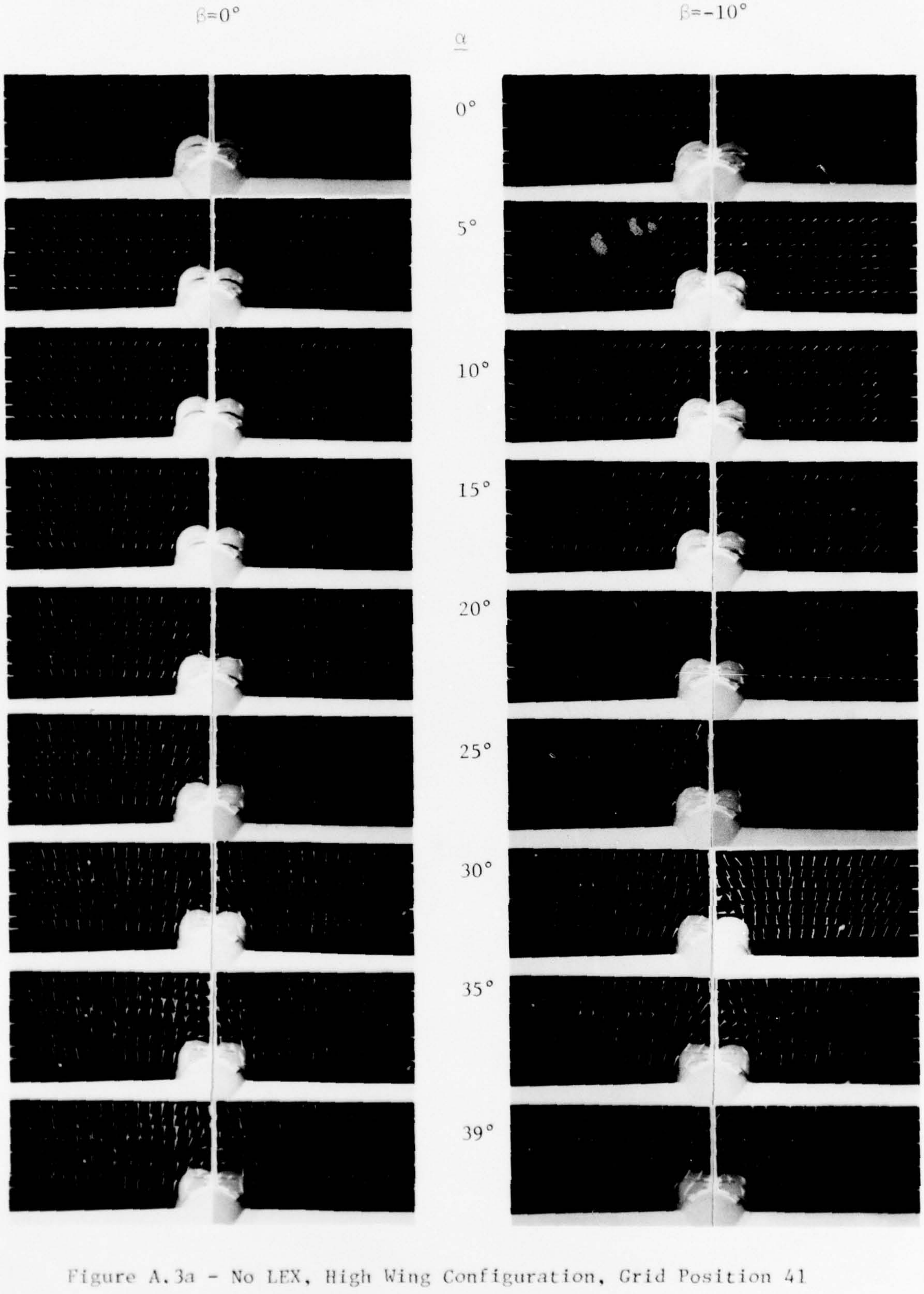


Figure A.3a - No LEX, High Wing Configuration, Grid Position 41

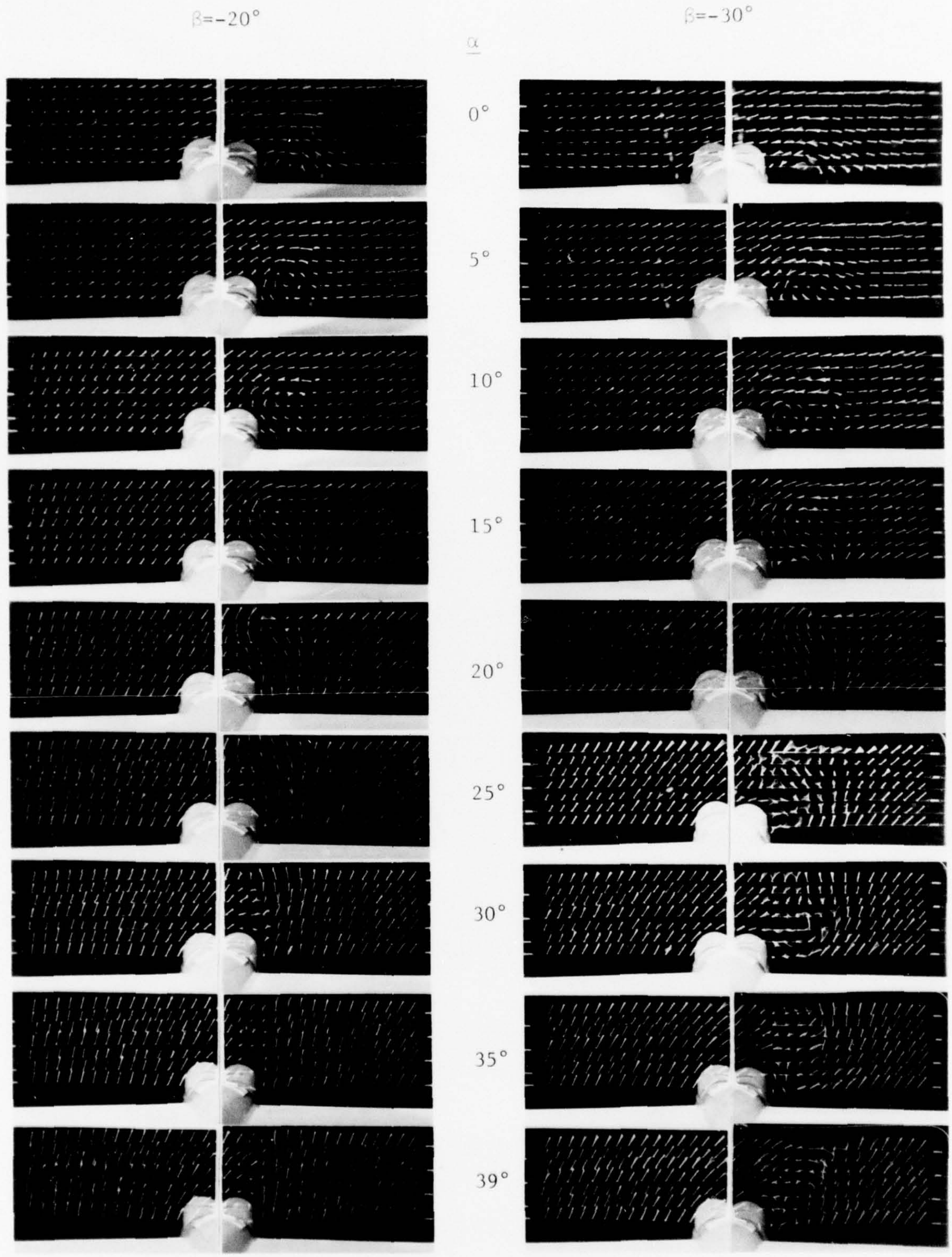


Figure A.3a (Continued)

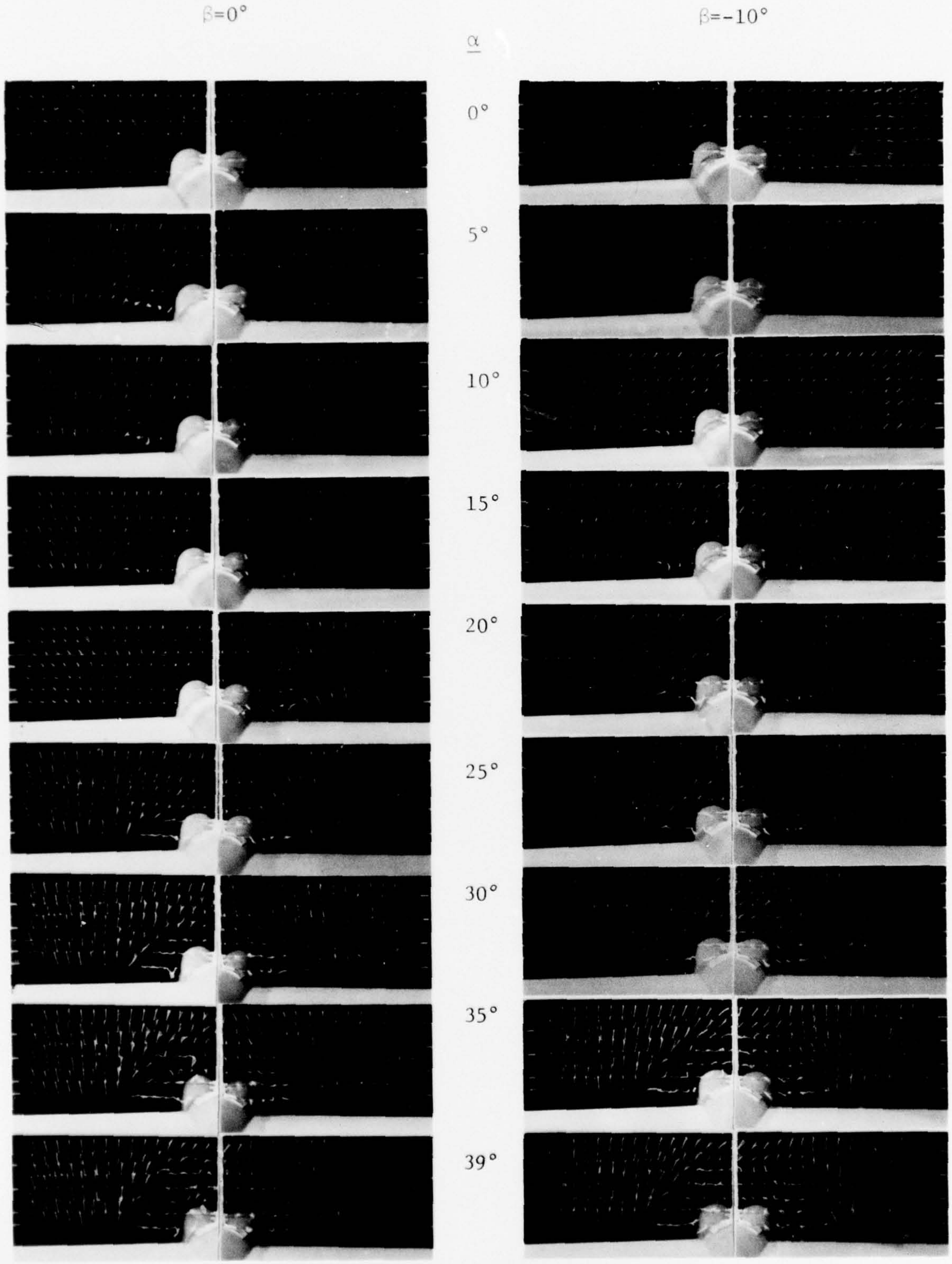


Figure A.3b - No LEX, High Wing Configuration, Grid Position 47

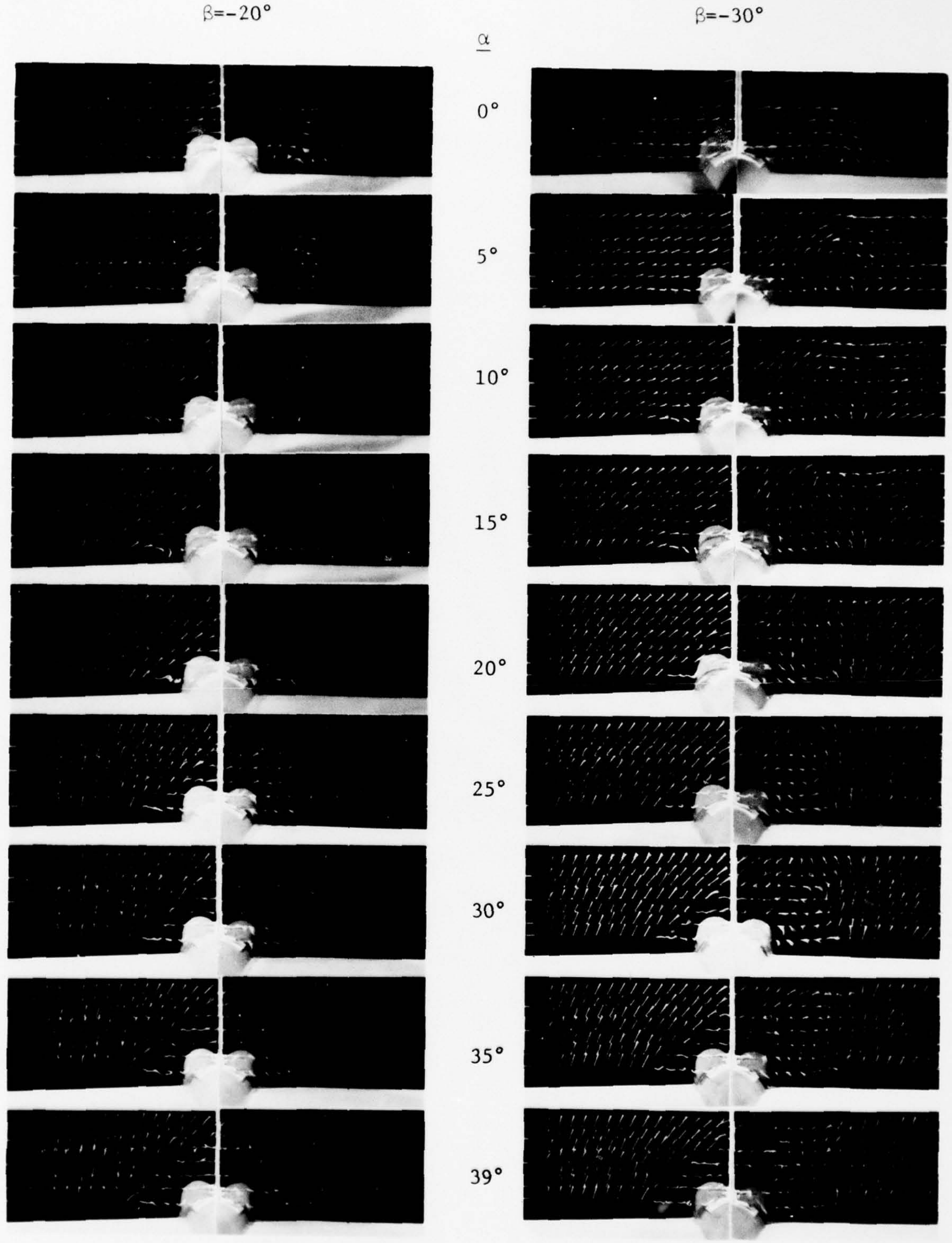


Figure A.3b (Continued)

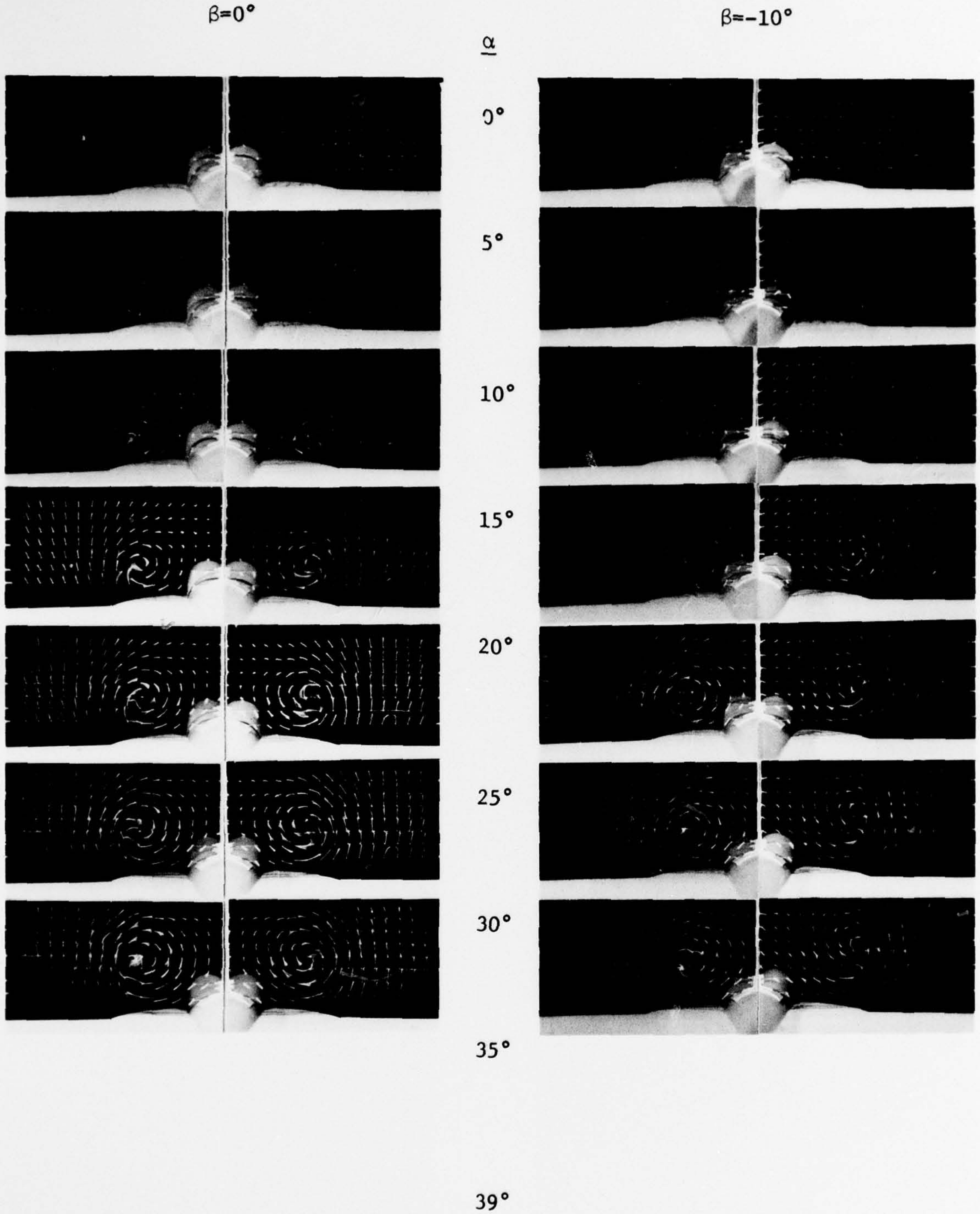


Figure A.4 - Ogive LEX, High Wing Configuration, Grid Position 41

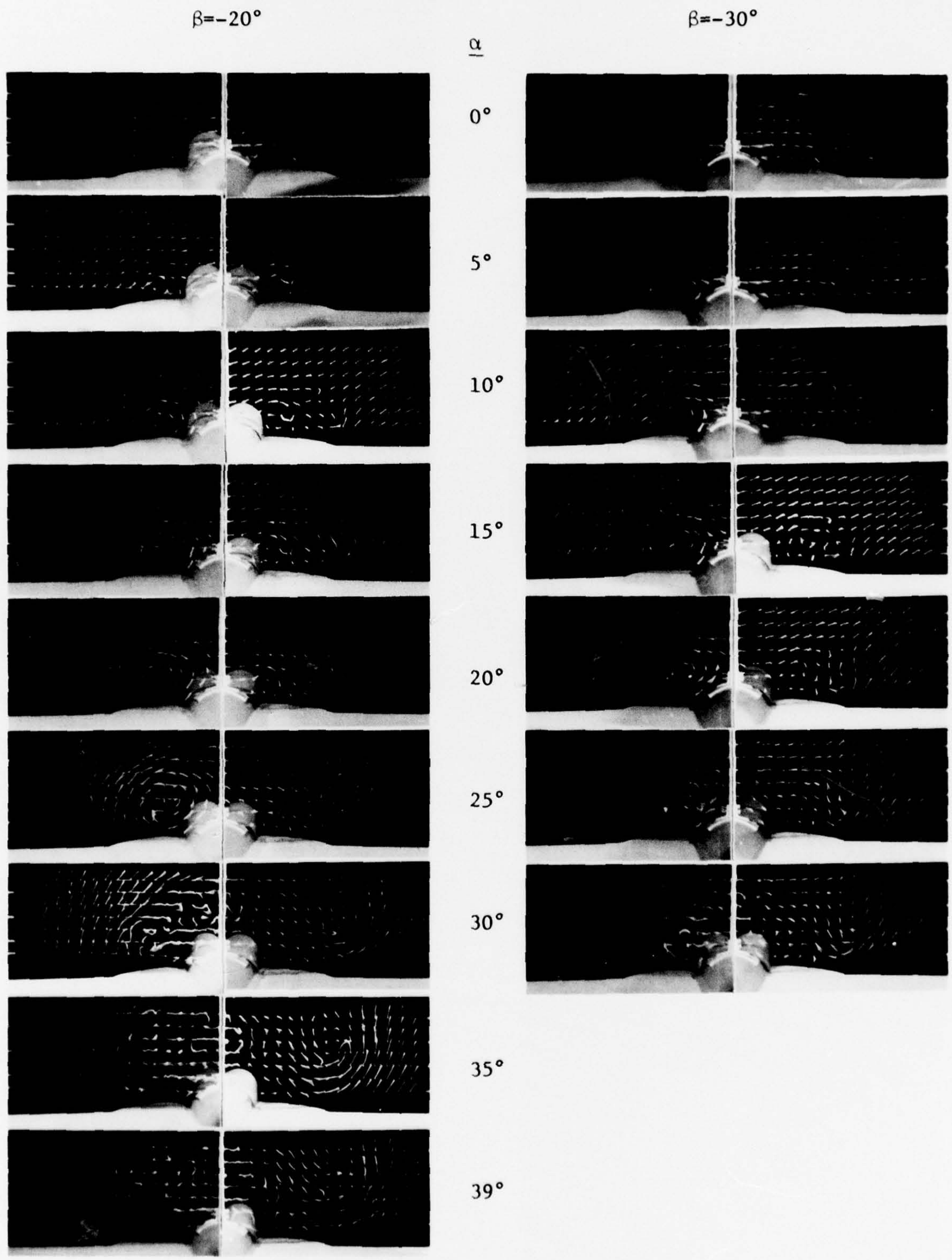


Figure A.4 (Continued)

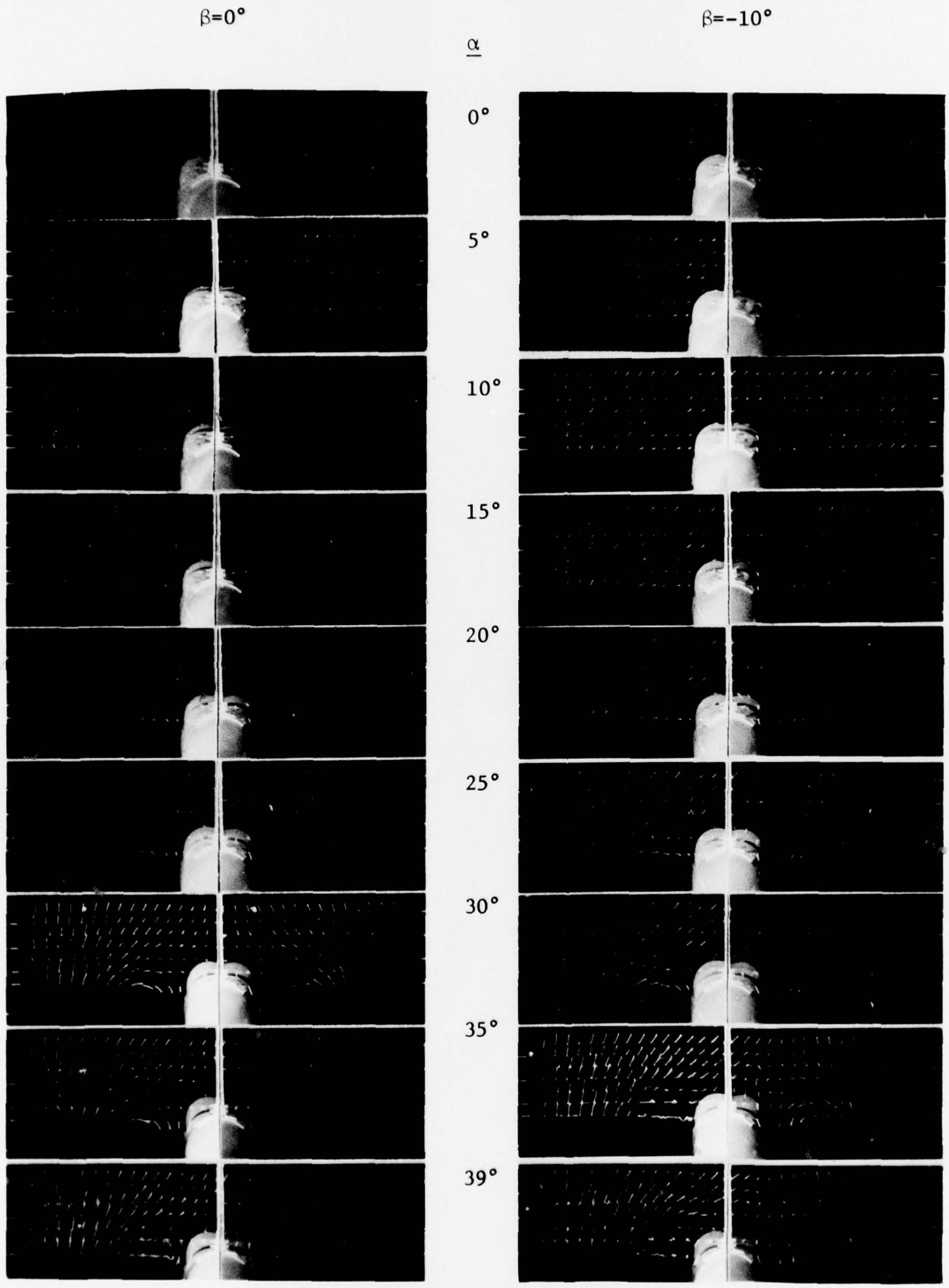


Figure A.5a - 75° LEX, Low Wing Configruation, Grid Position 35

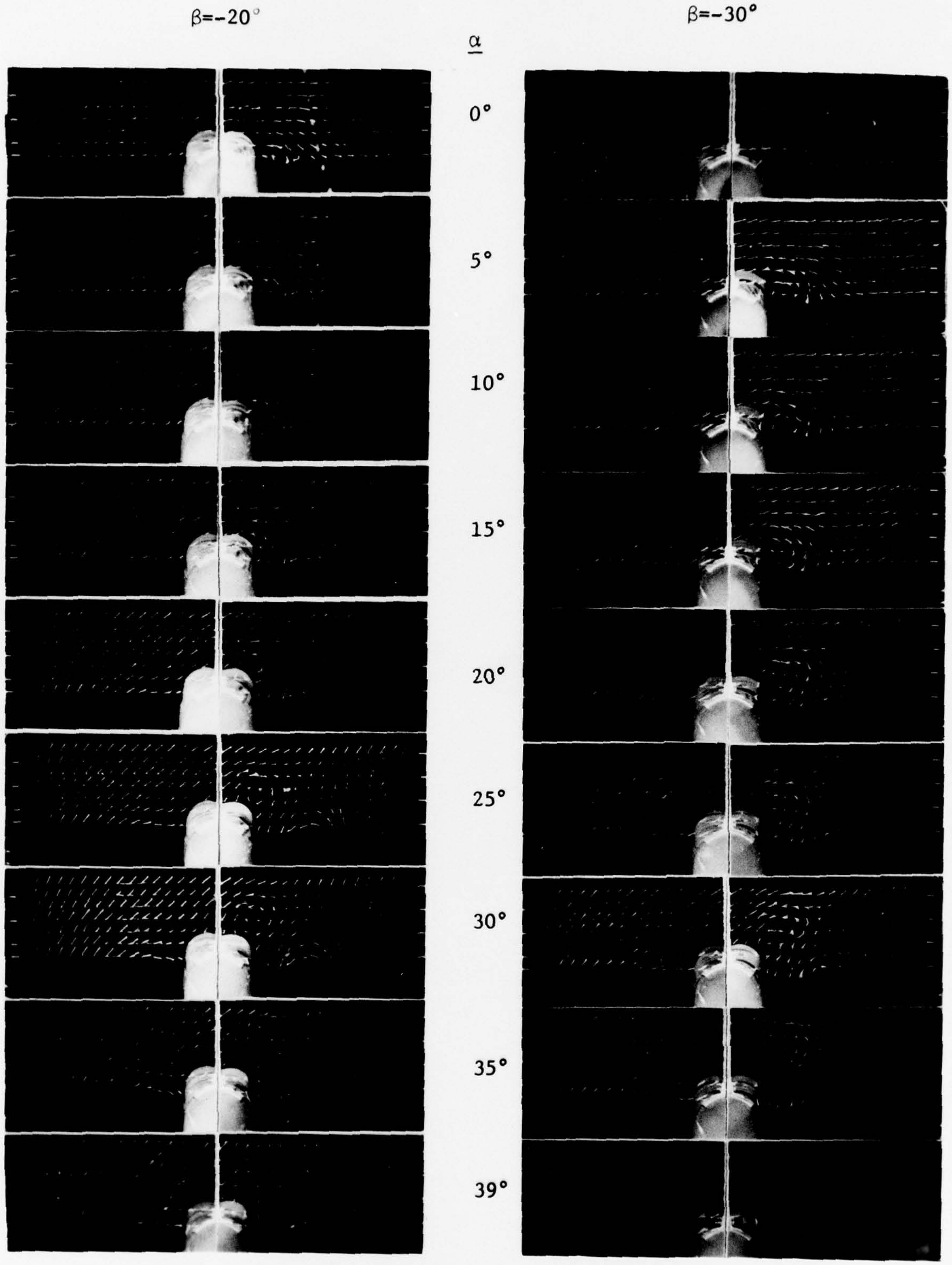


Figure A.5a (Continued)

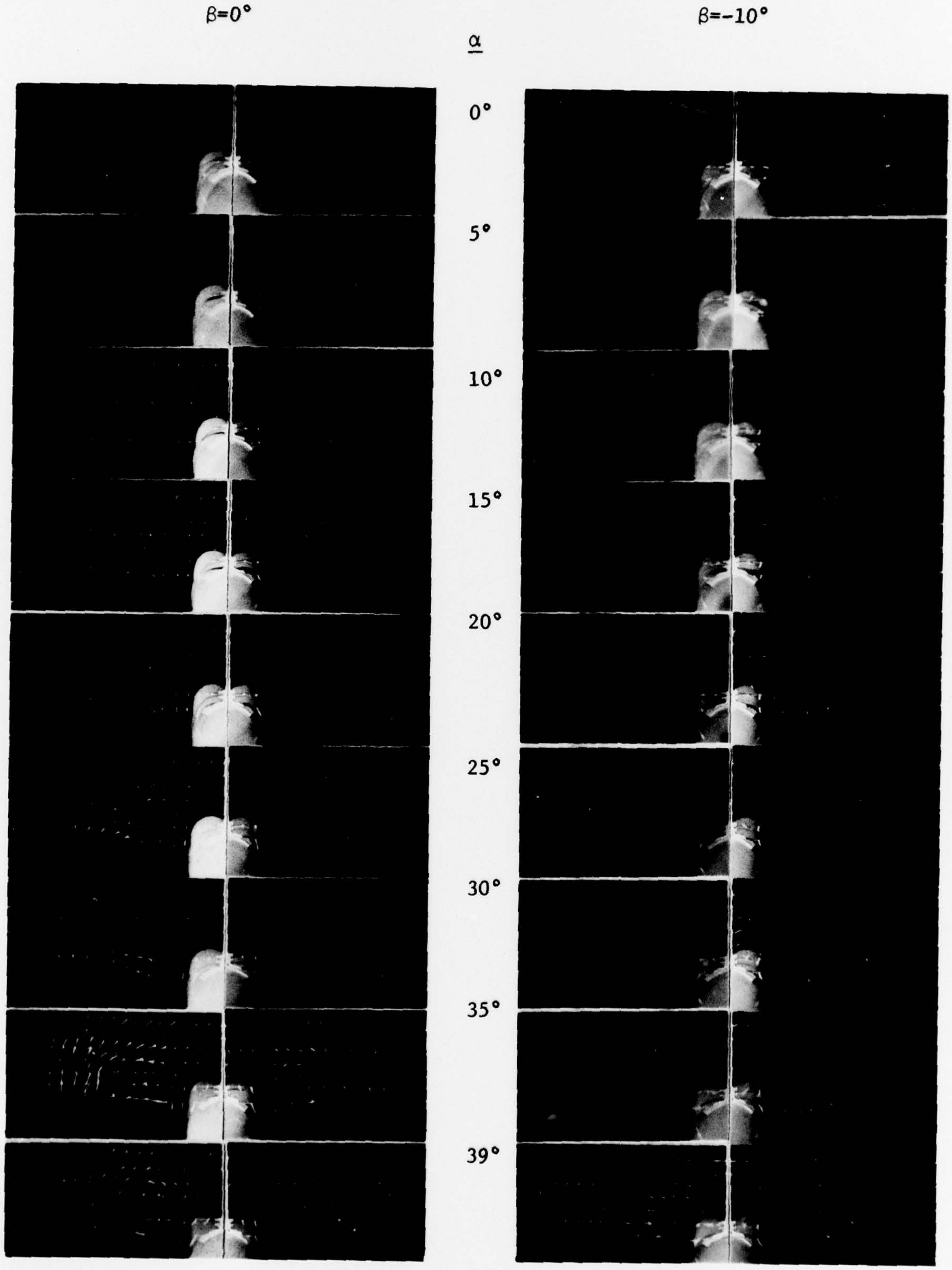


Figure A.5b - 75° LEX, Low Wing Configuration, Grid Position 41

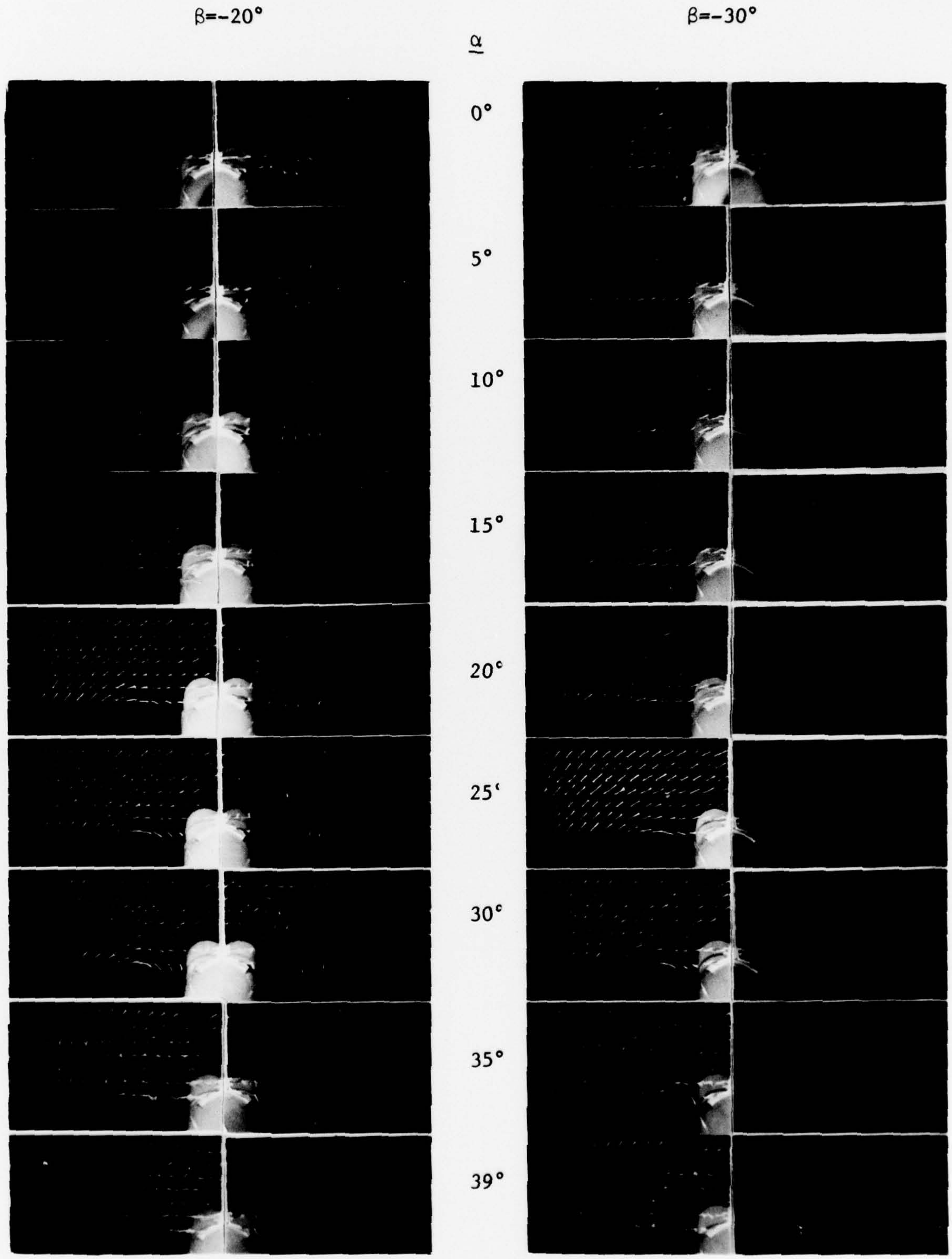


Figure A.5b (Continued)

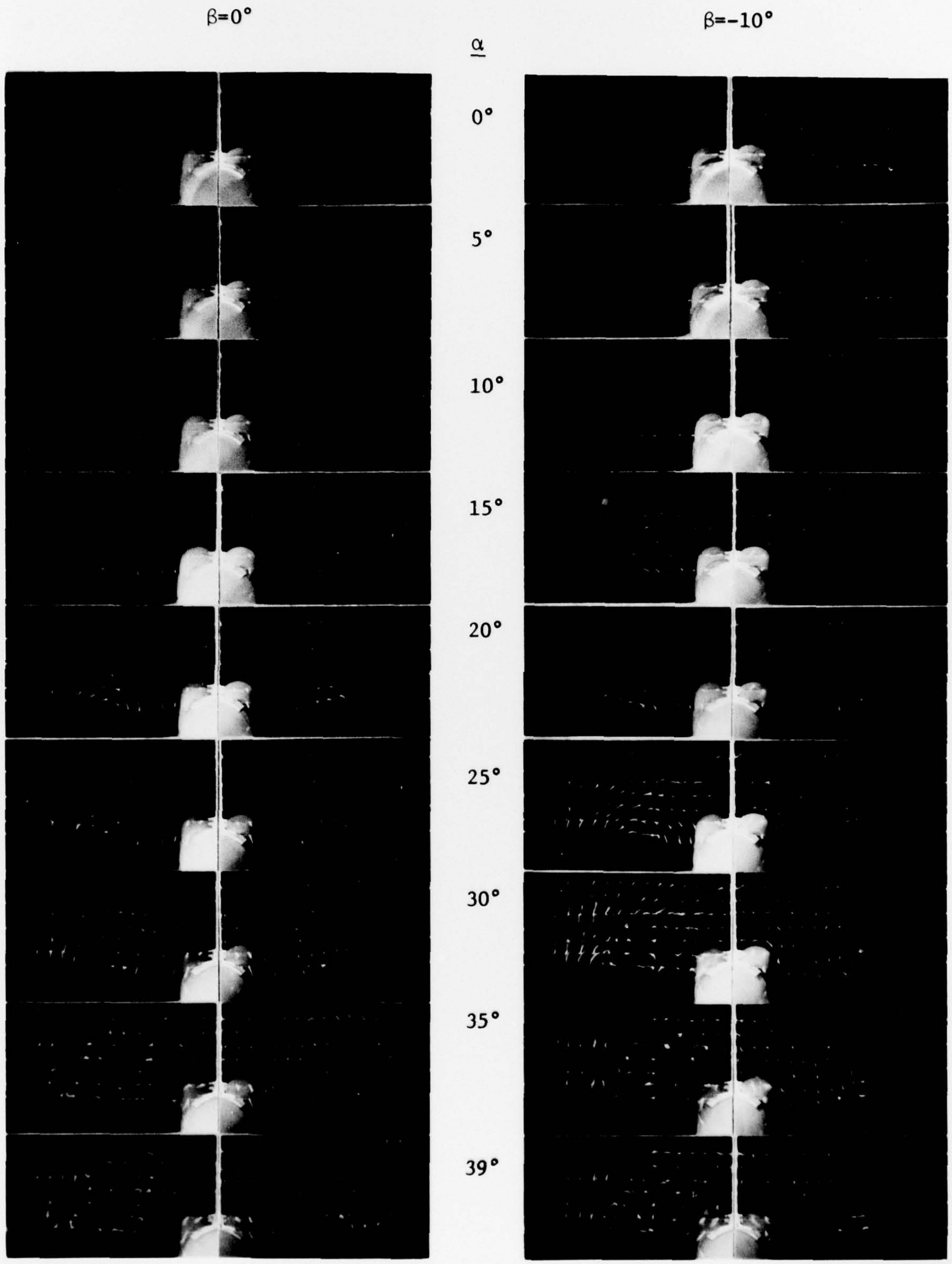


Figure A.5c - 75° LEX, Low Wing Configuration, Grid Position 47

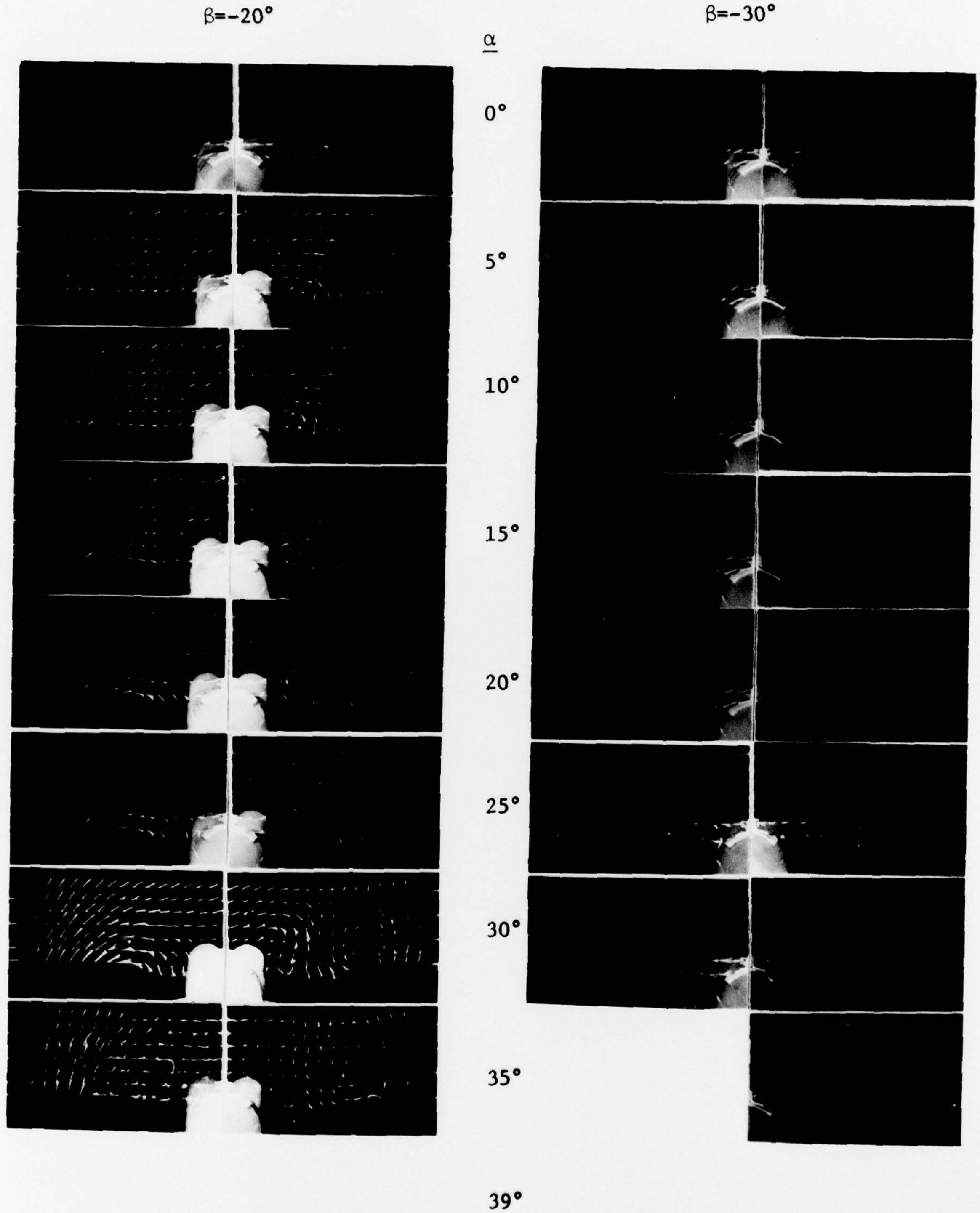


Figure A.5c (Continued)

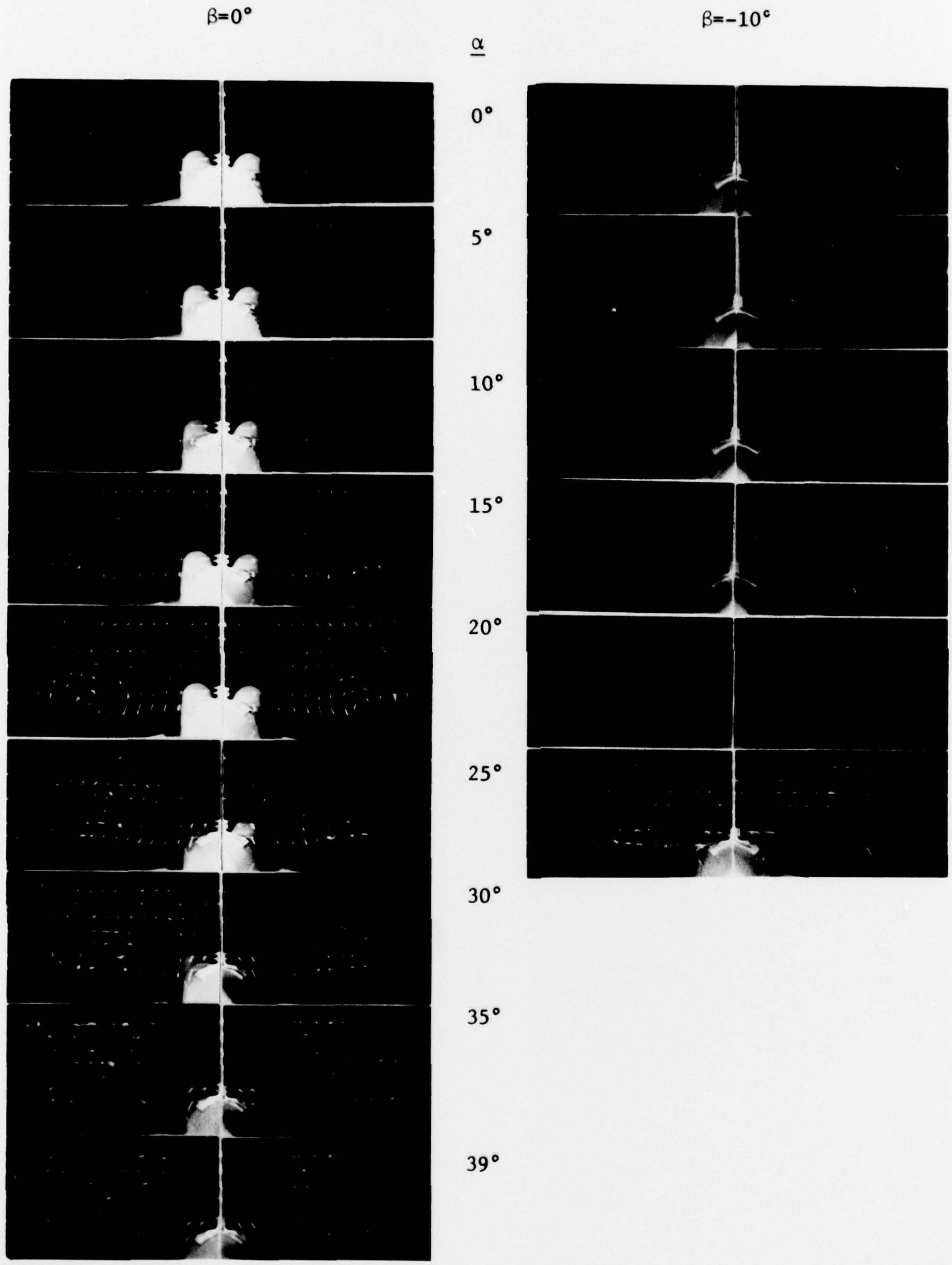


Figure A.5d - 75° LEX, Low Wing Configuration, Grid Position 55

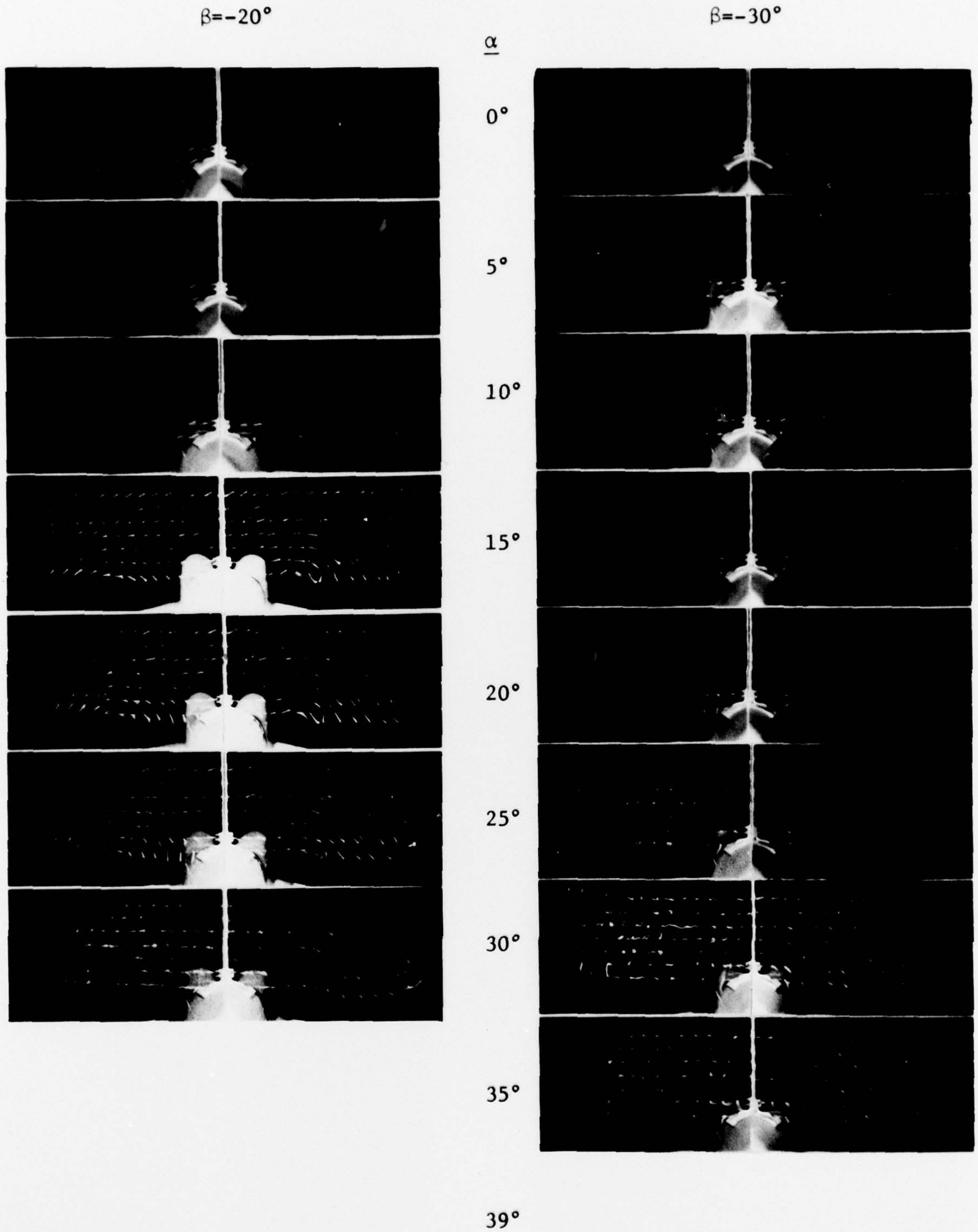


Figure A.5d (Continued)

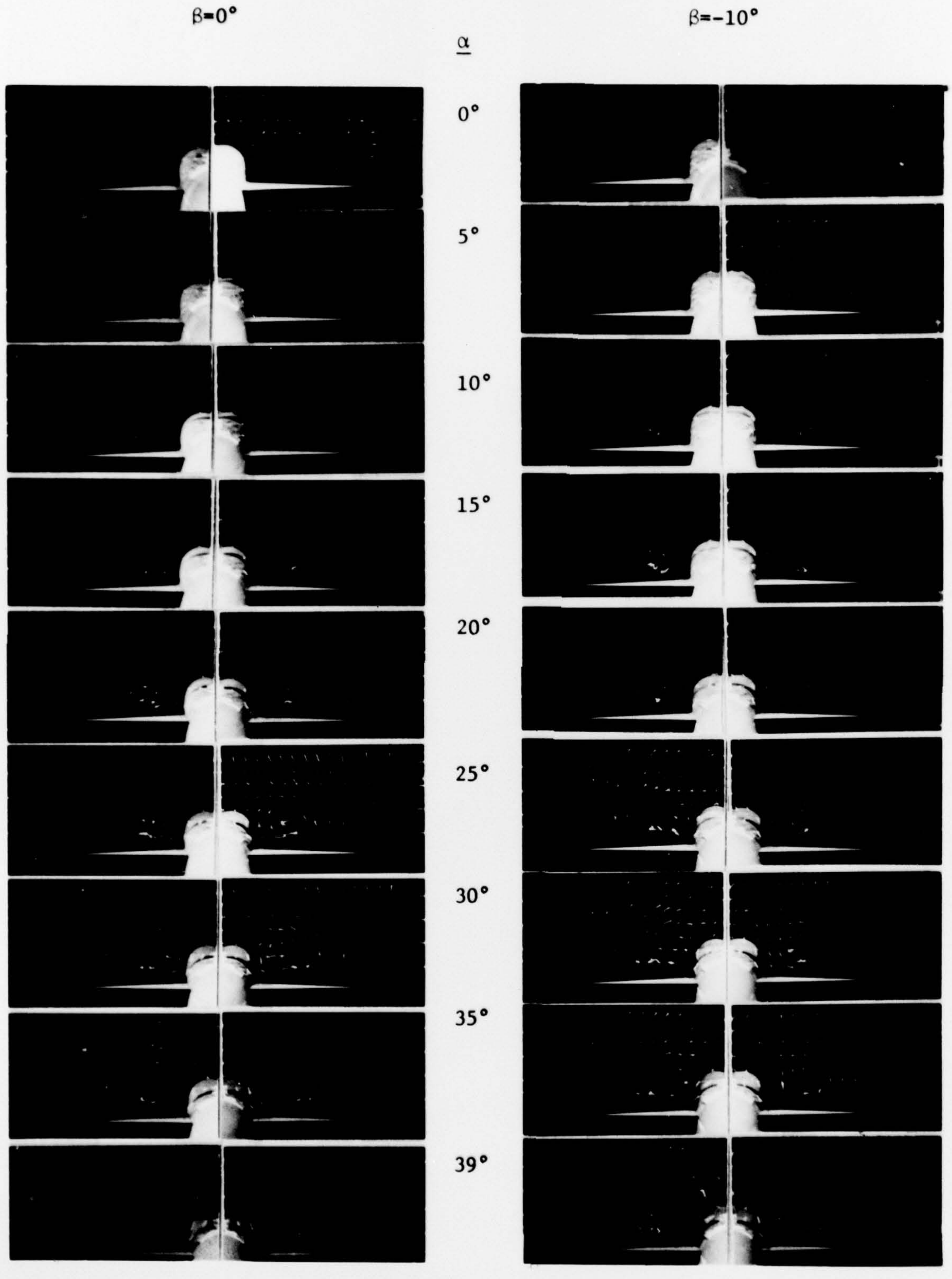


Figure A.6a - 60° Close Coupled Canard Configuration, Grid Position 35

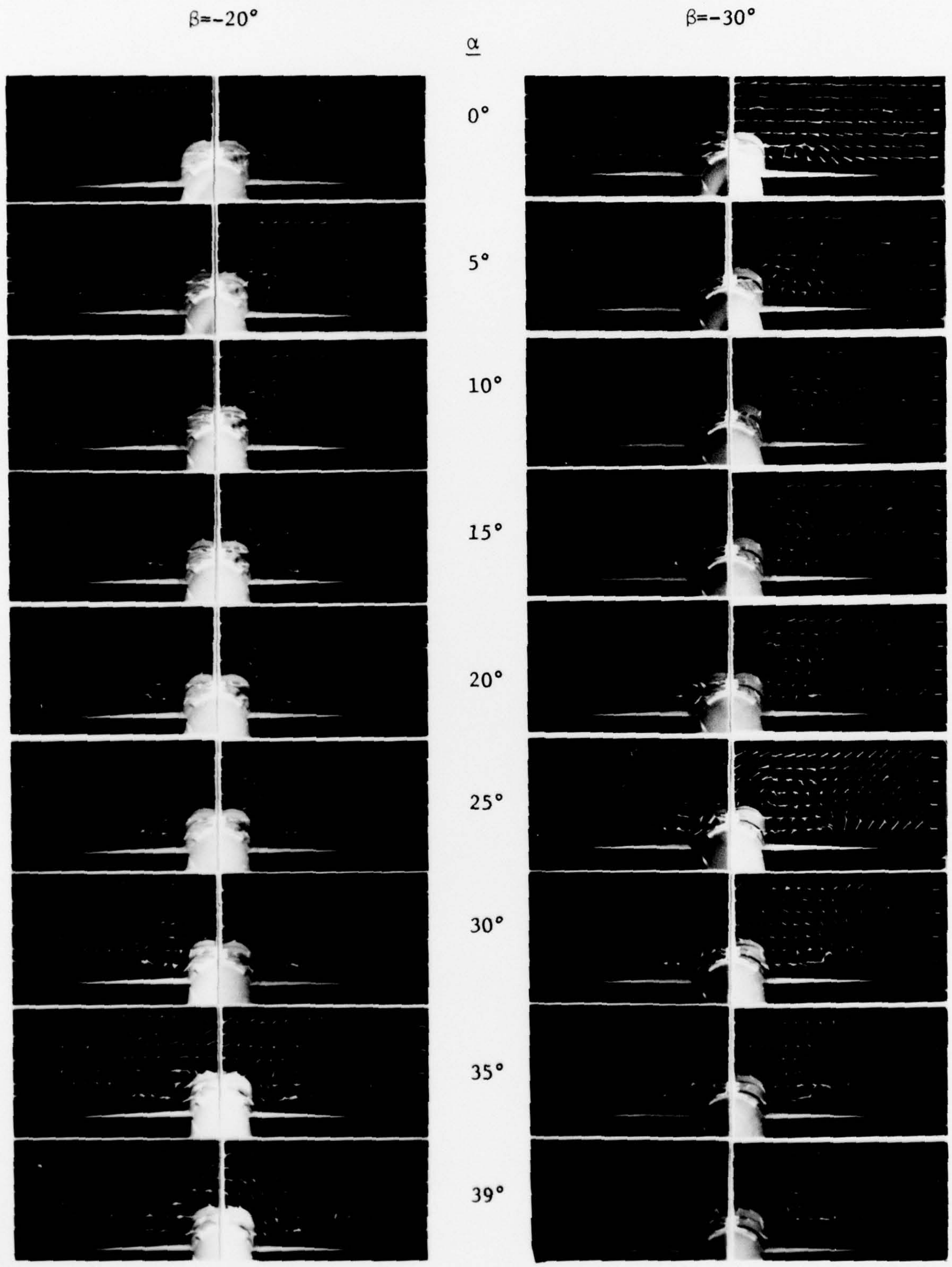


Figure A.6a (Continued)

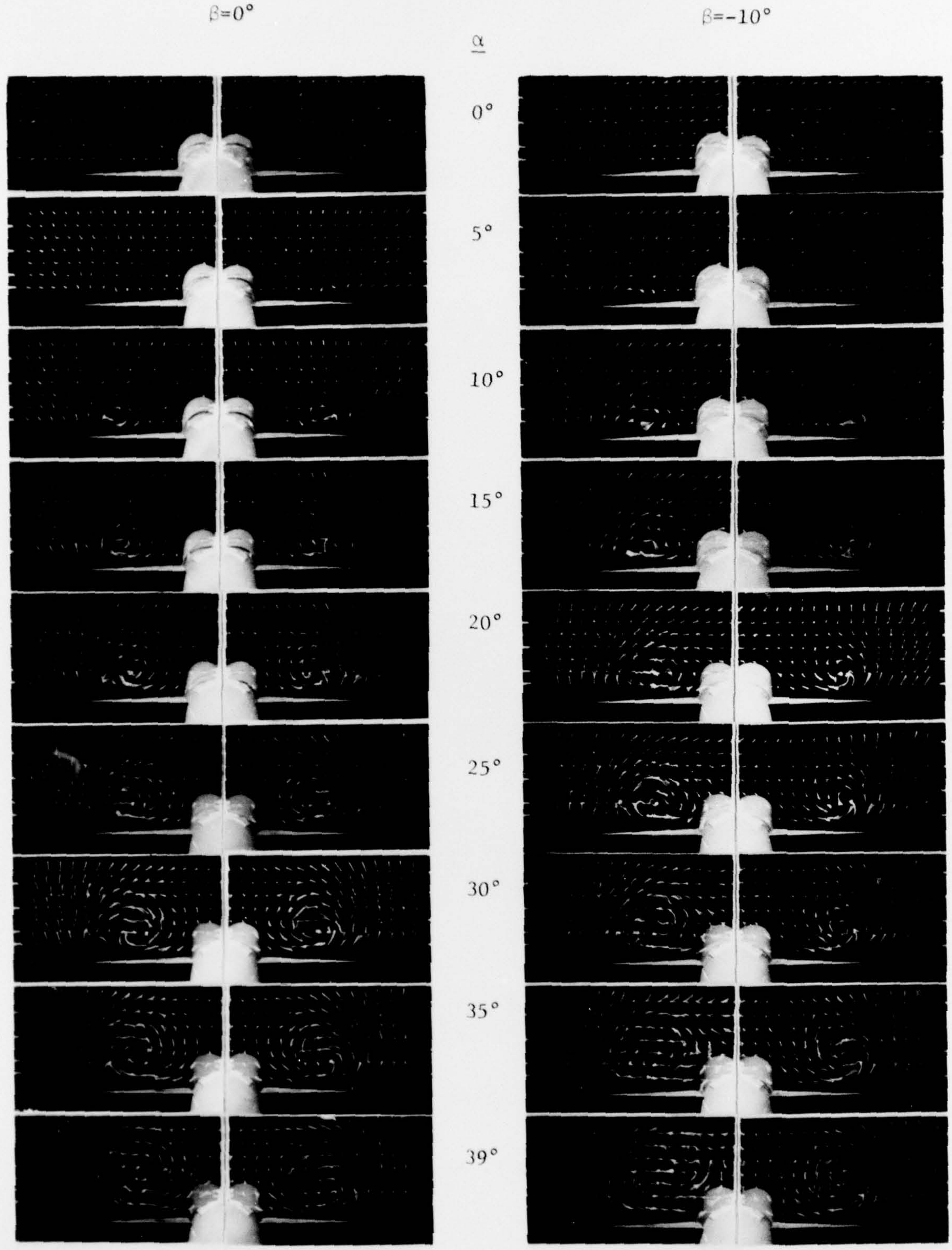


Figure A.6b - 60° Close Coupled Canard Configuration, Grid Position 41

β=-20° β=-30°

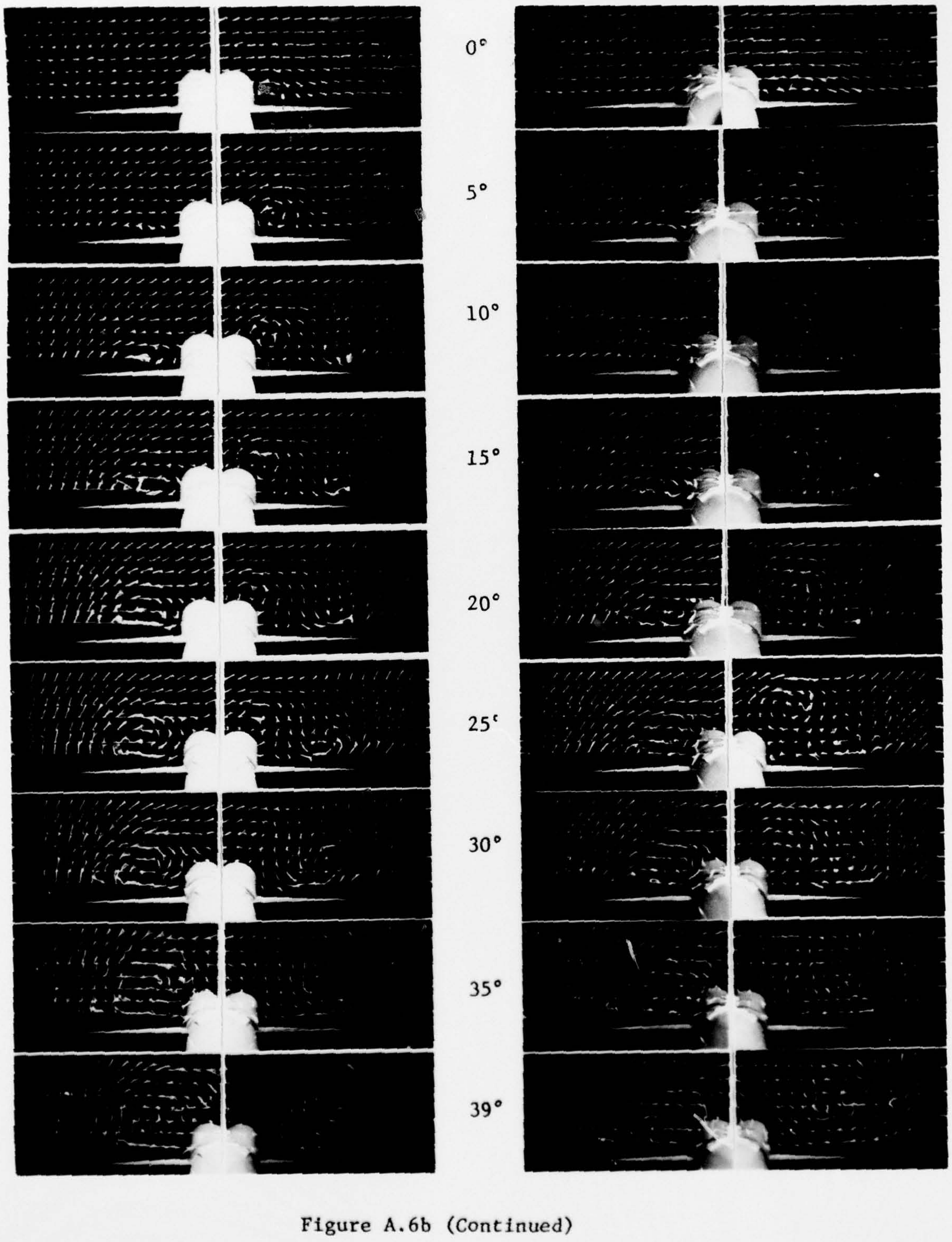


Figure A.6b (Continued)

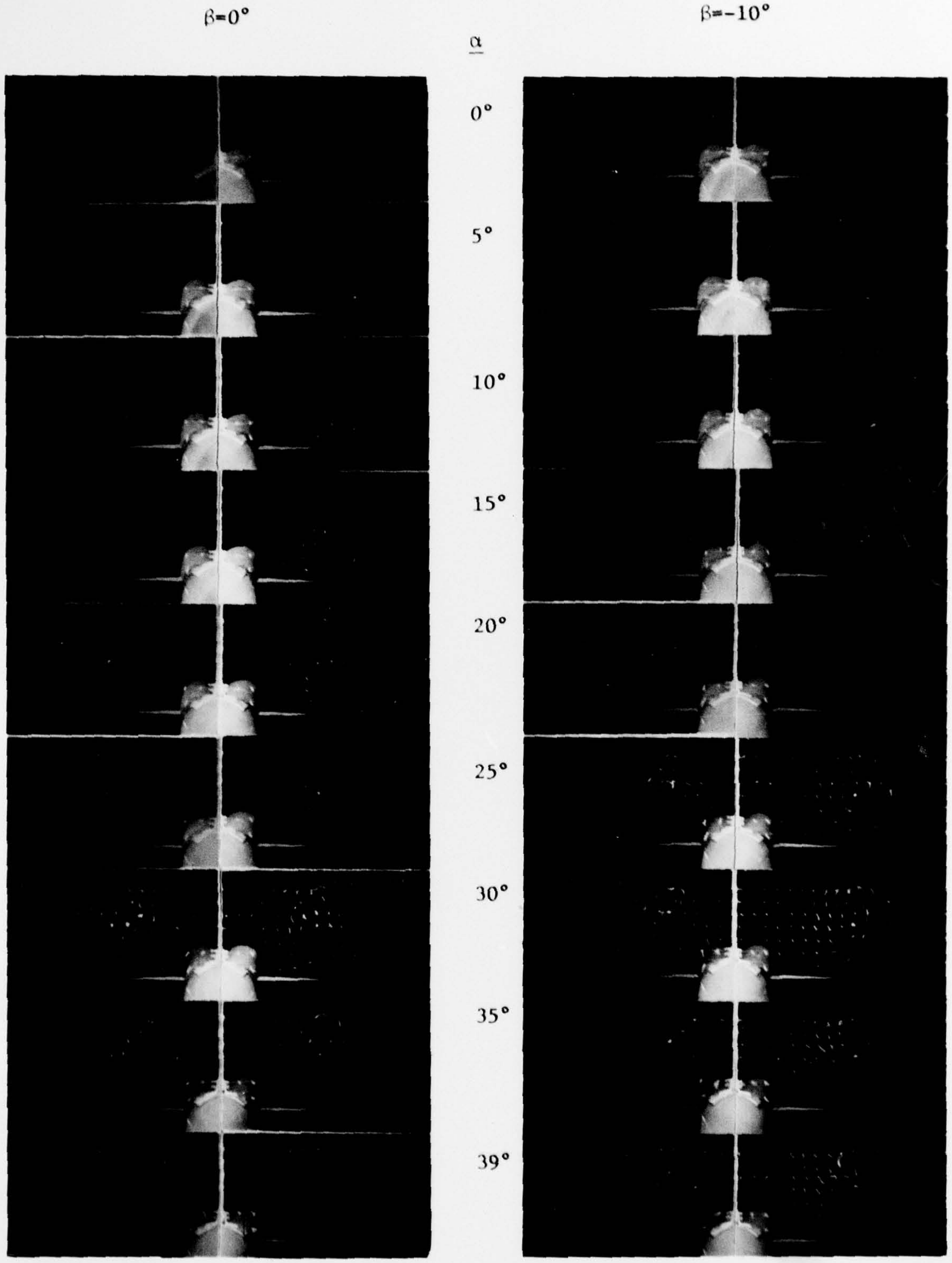
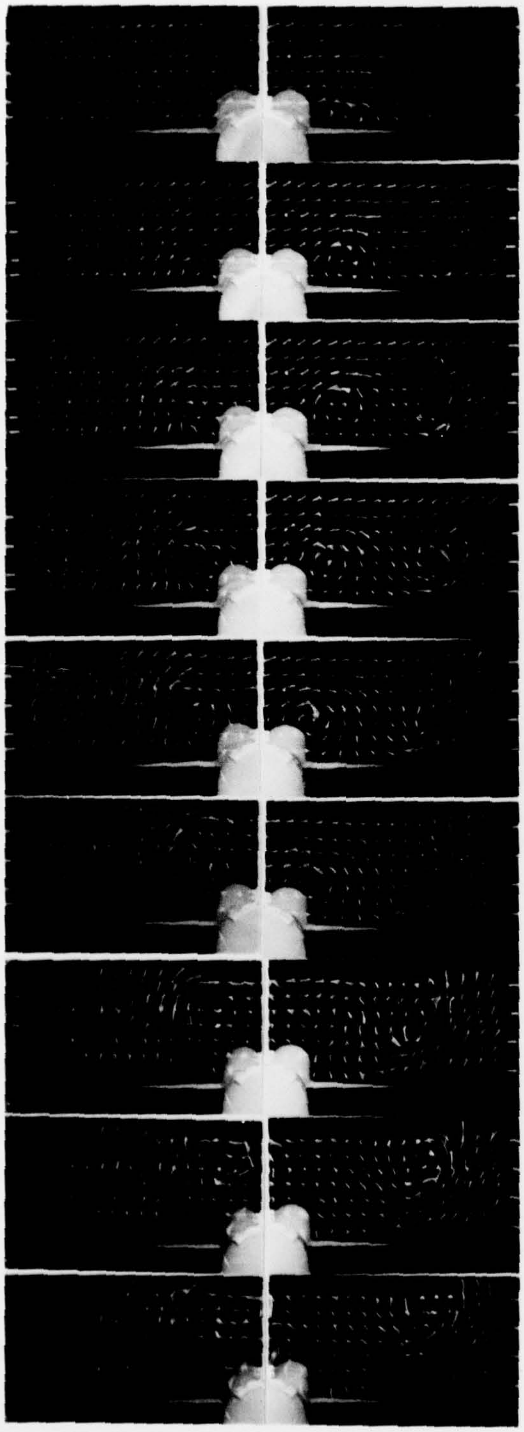


Figure A.6c - 60° Close Coupled Canard Configuration, Grid Position 47

$\beta=-20^\circ$ $\beta=-30^\circ$



$\underline{\alpha}$

0°

5°

10°

15°

20°

25°

30°

35°

39°

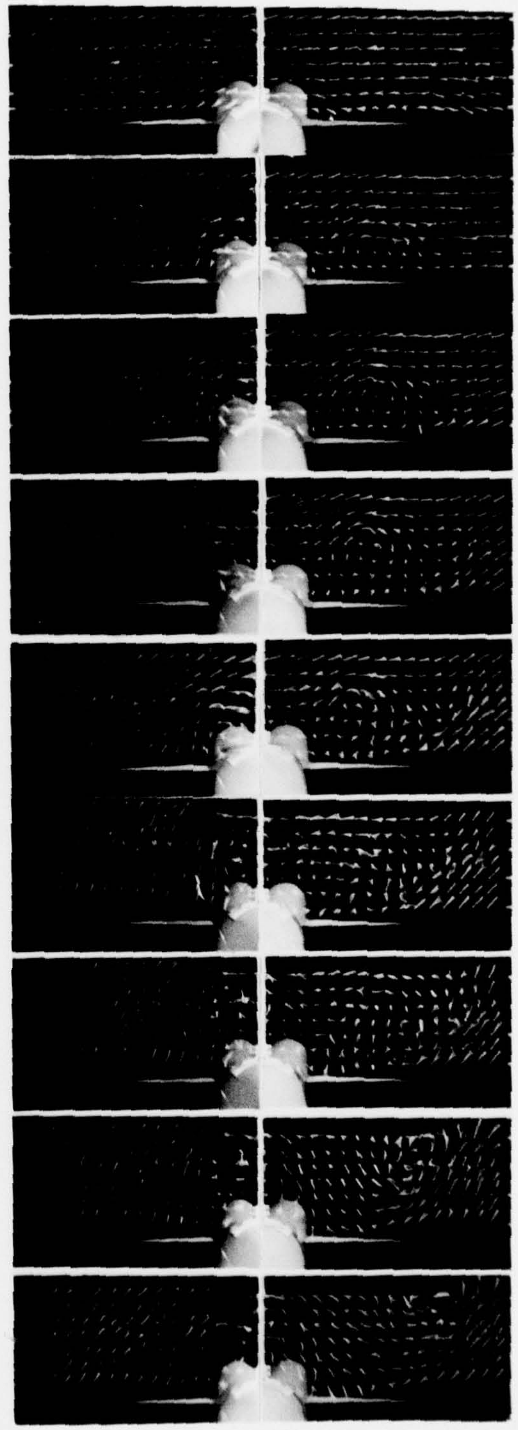


Figure A.6c (Continued)

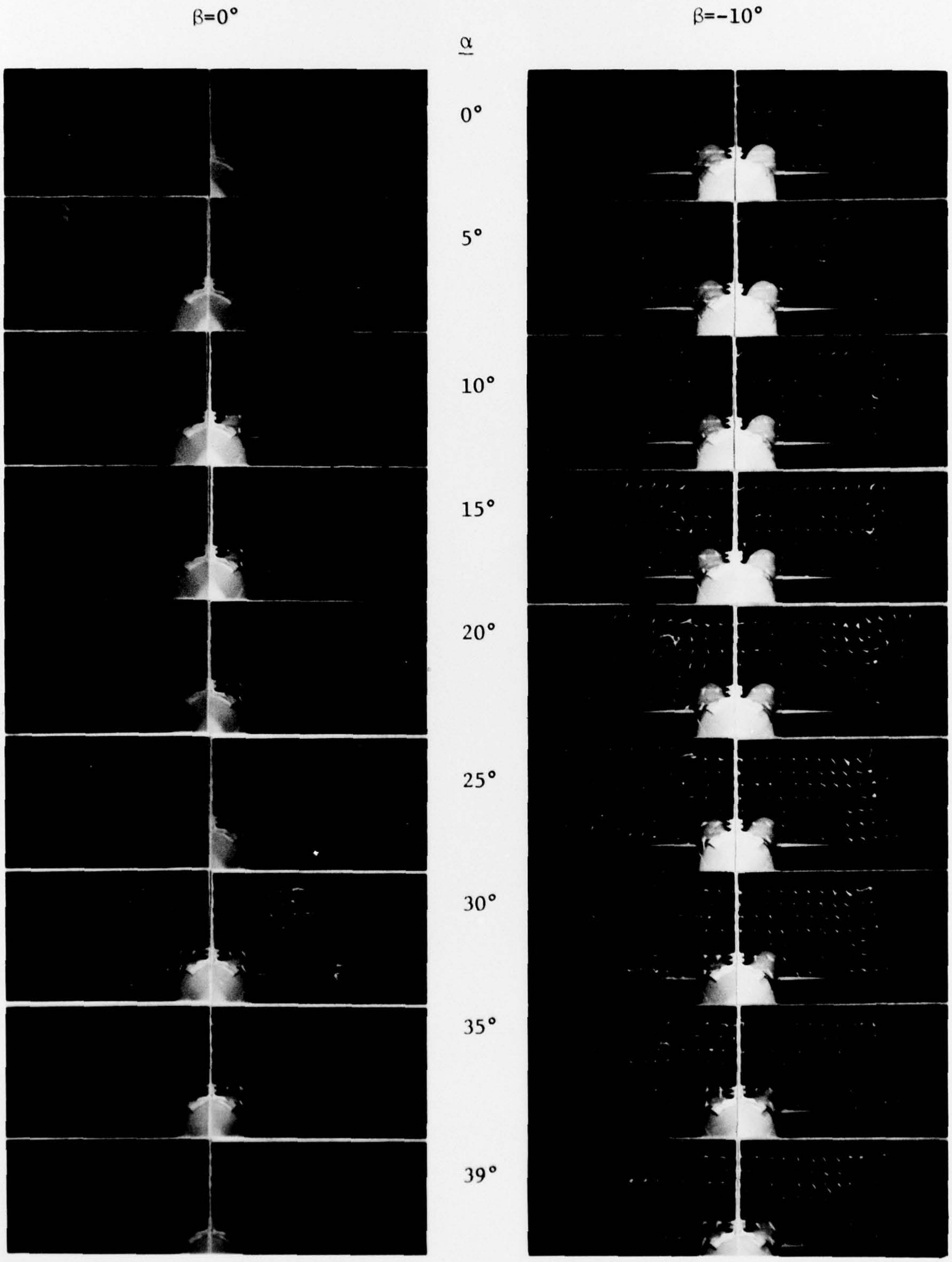


Figure A.6d - 60° Close Coupled Canard Configuration, Grid Position 55

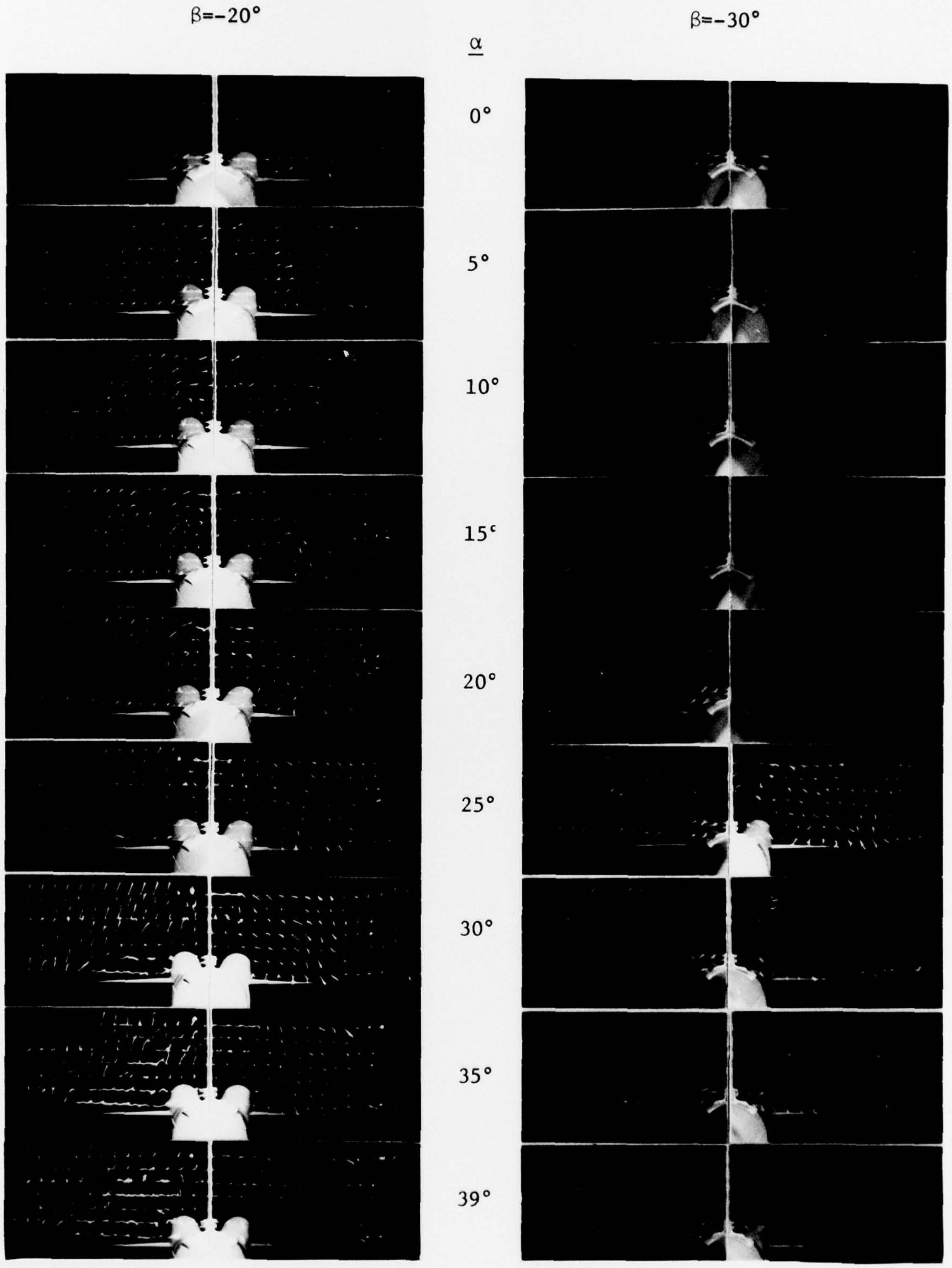


Figure A.6d (Contiued)

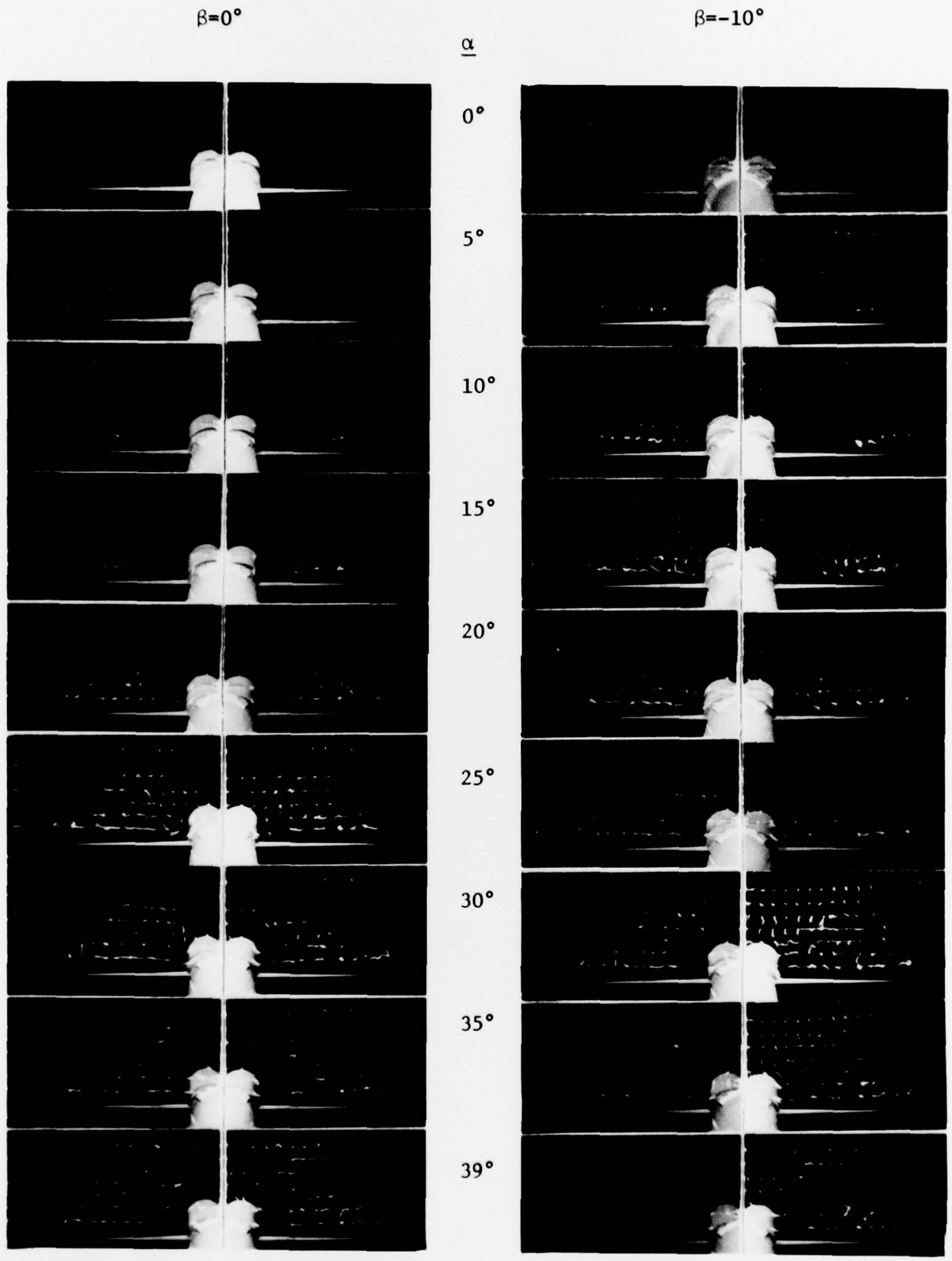


Figure A.7 - 45° Close Coupled Canard Configuration, Grid Position 41

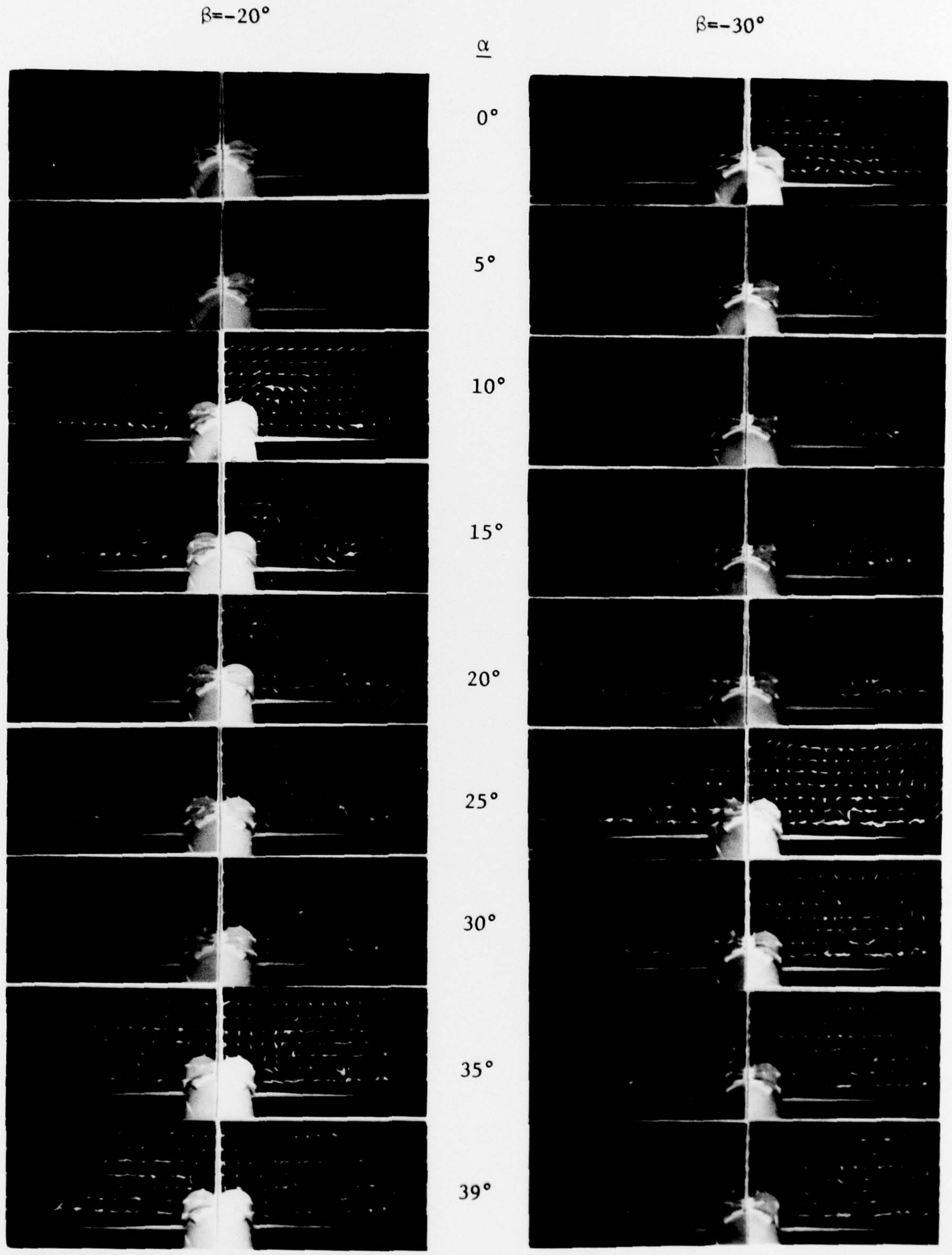


Figure A.7 (Continued)

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